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A WIND TUNNEL STUDY OF MAGNUS EFFECTS ON A DIFFERENTIALLY ROTATING MISSILE

THESIS

Karen A. Naselius, Captain, USAF
AFIT/GAE/ENY/92D-01

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A WIND TUNNEL STUDY OF MAGNUS EFFECTS ON A DIFFERENTIALLY ROTATING MISSILE

THESIS

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This study investigates Magnus effects on a non-finned missile model which had three axially rotating sections that spun at different rates. Five spin cases are examined; the mid section spinning only; the front and rear sections spinning only; all sections spinning at the same speed; all sections spinning in the same direction with the mid section spinning at an additional ten revolutions per second; and all sections spinning with the mid sections spinning in the opposite direction at an additional ten revolutions per second. These five cases are tested at three different spin rates for two different wind tunnel velocities. Since no research on differential spinning was found, potential flow theory of a single spinning cylinder is expanded to the differential spinning cases. Test results show that the measured Magnus forces and moments are much smaller than the potential flow predictions though most were in the predicted direction. Results also show that normal and axial forces are not affected by spin which agrees with potential flow theory.

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ACKNOWLEDGMENTS

When I decided I would do an experimental thesis, I knew it would be the most challenging and interesting type of thesis to do. Though I was warned that many things could go wrong and make it impossible to complete on time, I knew I wanted this "hands-on" experience. This thesis has been all I hoped for as well as all I dreaded; but I have learned more in completing this project than in all the classes combined. I would like to thank my advisor, Dr. Paul King for suggesting this thesis project and for his help in completing it.

Though only my name is on this thesis, in reality, it has been a team project. My greatest thanks go to Mr. Jim Grove of Wright Labratories; without his expertise of wind tunnel procedures and troubleshooting abilities, I would never have gotten any decent data from this experiment. My thanks to Mr. Tim Hancock whose expertise and innovation in making (and remaking) my model, made it possible to do this experiment. My thanks to Mr Dan Rioux who was always ready to run the tunnel for me, day or night. My thanks to Mr. Jay Anderson whose design ideas and knowledge of electronics enabled me to design the model. Finally, my thanks to my husband, Dan, for encouraging me and putting up with my rantings and ravings over this project..

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LIST OF SYMBOLS

A	Axial Force (lb_f)
AX	Axial Force Gage (lb_f)
c	Closed Curve
C	Wind Tunnel Test Section Area (ft^2)
C_A	Axial Force Coefficient
ΔC_{Ab}	Change in Axial Force Coefficient due to Buoyancy
C_L	Lift Coefficient
C_N	Normal Force Coefficient
C_{np}	Magnus Moment Coefficient
C_{yp}	Magnus Force Coefficient
C_{ypc}	Corrected Magnus Force Coefficient
d	Model Diameter (ft)
dp/dl	Longitudinal Static Pressure Gradient
K	Body Shape Factor
L	Lift (lb_f)
l	Length of Cylinder (ft)
l_{eff}	Effective Length of Cylinder (ft)
l_n	Length of the Model Nose Cone (ft)

l_b	Length of the Model Body (ft)
M	Mach Number
N	Normal Force (lb_f)
N_0	Normal Force for Nonspinning Case (lb_f)
N_s	Beta Induced Yaw Force (lb_f)
N1	Normal Force Element 1 Gage (lb_f)
N2	Normal Force Element 2 Gage (lb_f)
n_p	Magnus Moment (ft-lb_f)
n_{pc}	Corrected Magnus Moment (ft-lb_f)
q	Corrected Dynamic Pressure (lb_f/ft^2)
Q	MeasuredDynamic Pressure (lb_f/ft^2)
p	Spin Rate (rev/sec)
p_{eff}	Effective Spin Rate (rev/sec)
Δp	Increment Change in Spin Rate (rev/sec)
r	Radius (ft)
Re_l	Reynolds Number ($\rho V l/\mu$)
RM	Rolling Moment Gage (in-lb_f)
S_l	Reference Area based on Length ($2rl$) (ft^2)
$S_{l\,eff}$	Reference Area based on Effective Length ($2rl_{eff}$) (ft^2)
S_r	Reference Area based on Radius (πr^2) (ft^2)
V	Velocity (ft/sec)
VR	Velocity Ratio ($2\pi pr/V$)
Y1	Yaw Force Element 1 Gage (lb_f)
Y2	Yaw Force Element 2 Gage (lb_f)
Y_p	Magnus Force (lb_f)

Y_{pc}	Corrected Magnus Force (lb_f)
ΔY_p	Magnus Force based on Δp (lb_f)
x	Distance between Model CG and Center of Pressure
$\bar{x},\bar{y},\bar{z}$	Distances from Balance cg. to Model cg.
X,Y,Z	Axes of the Body Reference Frame
α	Angle of Attack (degrees)
Γ	Circulation (per unit length) (ft^2/sec)
ρ	Density of Air (lb_f-sec^2/ft^4)
ε_{sb}	Solid Blockage Factor
μ	Coefficient of Viscosity of the Air (lb_f-sec/ft^2)
$(\ )_f$	Designates Front Section of Cylinder
$(\ )_{(p+\Delta p)}$	Designates Front Section Spinning Faster than the Rear in the Same Direction
$(\ )_{-(p+\Delta p)}$	Designates Front Section Spinning Faster than the Rear in the Opp. Direction
$(\ )_r$	Designates Rear Section of Cylinder

ABSTRACT

This study investigates Magnus effects on a non-finned missile model which had three axially rotating sections that spun at different rates. Five spin cases are examined; the mid section spinning only; the front and rear sections spinning only; all sections spinning at the same speed; all sections spinning in the same direction with the mid section spinning at an additional 10 rev/sec; and all sections spinning with the mid section spinning in the opposite direction at an additional 10 rev/sec. These five cases are tested at three different spin rates for two different wind tunnel velocities. Since no research on differential spinning was found, potential flow theory of a single spinning cylinder is expanded to the differential spinning cases. Test results show that the measured Magnus forces and moments are much smaller than the potential flow predictions though most were in the predicted direction. Results also show that normal and axial forces are not affected by spin which agrees with potential flow theory.

A WIND TUNNEL STUDY OF MAGNUS EFFECTS ON A DIFFERENTIALLY ROTATING MISSILE

I. INTRODUCTION

In circulation theory, a spinning cylinder generates a side force in the direction normal to the free stream flow which is commonly called a Magnus force (Figure 1-1) (7:388). When studying missile motion, this side force along with the moment it produces, can if not taken into account, cause the missile to drift off it's trajectory. Magnus effects have been studied by many, but only in the realm of a single spinning cylinder. When a missile with three axially spinning sections rotate at different rates, the magnitude and direction of Magnus effects are unknown.

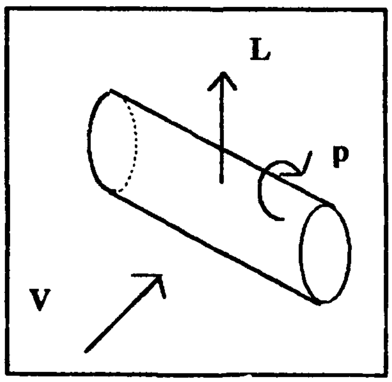

Figure 1-1. Magnus Force

This experiment was based on the Folding Fin Aircraft Rocket (FFAR) program whose payload section spins axially at a different rate than the rest of the rotating missile. The missile is 77 inches long with a 2.75 inch diameter and has a maximum rotation rate of 26 revolutions per second (rps) with the payload section differential rate in the range of +/-

15 rps. When the FFAR program was estimating the Magnus effects on it's missile, the data used was for a 2D single spinning cylinder (Figure 1-2) (6:10) which was not directly applicable to this missile. The objective of this experiment was to provide the FFAR program with realistic Magnus effect data based on an approximate 1/2 scale model of the FFAR as well as get a basic understanding of differential Magnus effects.

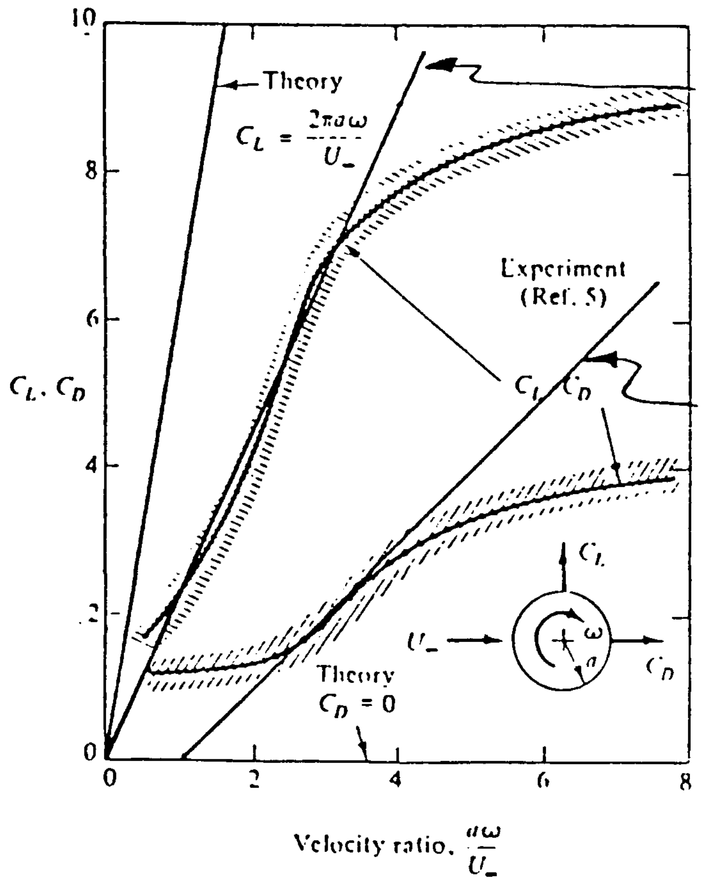

Figure 1-2. Data on a Rotating Cylinder (6:26)

II. TEST MODEL AND INSTRUMENTATION

Test Model

The test model shown in Figure 2-1, was a 0.47 scale model of the FFAR. It consisted of a solid aluminum shaft with three composit cylindrical shells which rotated axially at different rates. The three shells reflect the nose cone, the payload section and the motor case section of the FFAR. In this study, they are referred to as the front, mid, and rear sections, respectively.

Shells. The shells were tubular cylinders that were constructed by spiral wrapping fiberglass and graphite sheets. A fiberglass sheet of 0.09 inch thickness was wrapped at 30 degrees off axis then a graphite sheet of the same thickness was wrapped 180 degrees opposite to the fiberglass. The thickness of each shell was 0.18 inches which gave an outside diameter of 1.305 inches and an inner diameter of 1.125 inches. The mid section was a length of 12.375 inches as scaled to the payload section of the FFAR. The rear section was a length of 20.0 inches of which 0.5 inch was a brass cylinder. The front section was a sharp cone shape of length 2.15 inches with an inclued angle of 33.6 degrees plus 1.1 inch of cylinder length (Figure 2-1). This allowed the front section to be driven directly (discussed under Motors).

Aluminum Shaft. The aluminum shaft was made from 7075-T7 aircraft grade aluminum with a length of 28.062 inches (Figure 2-3). The front of the shaft was hollowed out to a depth of about two inches for the front motor to sit in. An end cap of

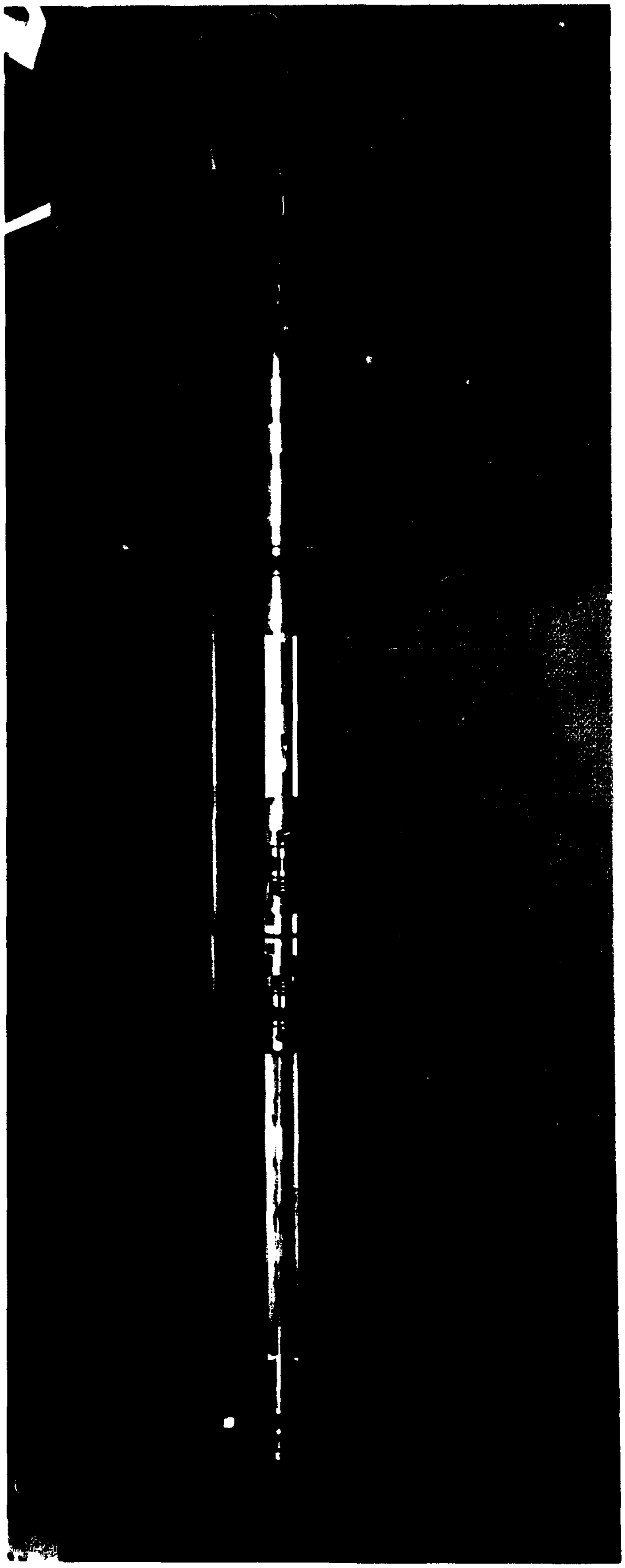

Figure 2-1 Test Model

0.0625 inch thickness was placed over the motor to keep it from coming out of the pocket. To drive the other sections, one motor was used in the mid section and two in the rear section. For each motor, a circular cutout of 0.3543 inch radius depth and 1.625 inches long, as shown in Figure 2-3. In the mid section area between the enclosed front motor and the mid section motor, the shaft was turned down to a 0.4375 inch diameter. This was done to lighten the mid section and move the center of gravity toward the rear. To give strength back to this section, four seven inch long balsa wood struts were attached in this region. In the area between the two rear section motors, the shaft was cut into an I-beam configuration to lighten the model weight also. The last cut out in the shaft was for the balance. The rear of the shaft was hollowed out to a depth of 4.308 inches with a diameter of 0.687 inch. Inside of this area, a balance receiver was placed. It was made of brass with a length of 2.813 inches, width of 0.687 inch and a thickness of 0.0935 inch. This was done because the balance gives better readings when fitted against brass.

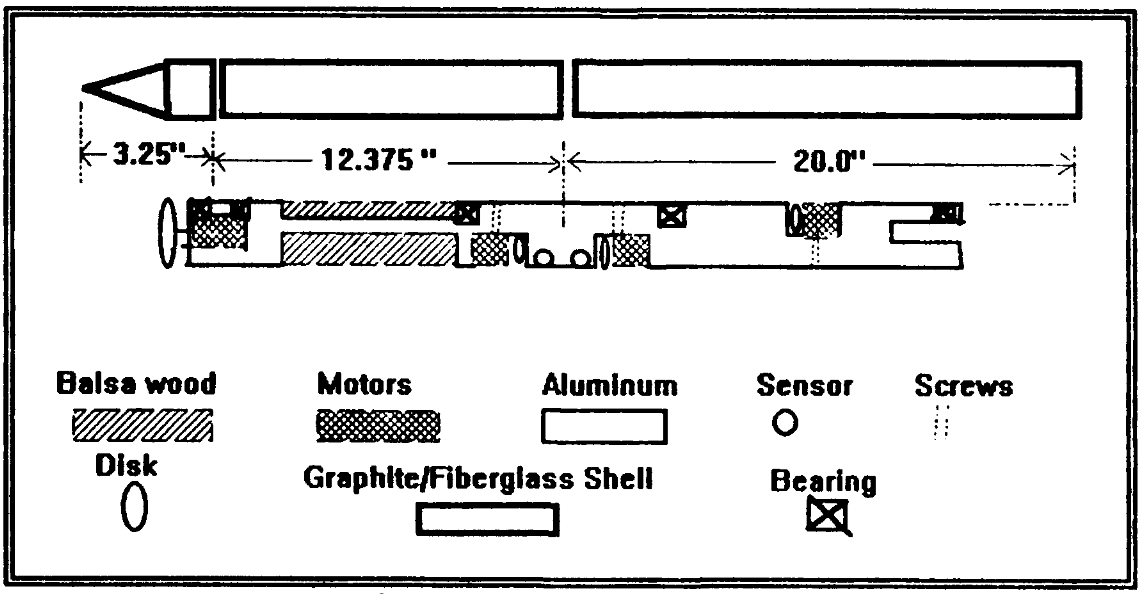

Figure 2-2. Model Design Layout

Motors. The motors were 18 mm in diameter, ironless rotor DC motors (4:77). Attached to each motor was a 0.6875 inch diameter aluminum disk with a thickness of 0.156 inch. A groove was made in each disk to allow a 0.5 inch diameter plastic O-ring to sit securely on the disk. The O-ring rubbed the interior of the shell and the shell turned due to the friction. To adjust the amount of O-ring contact, a set screw was drilled through the shaft opposite each motor. This screw was then used to adjust the motor up or down for the O-ring to have optimum contact with the shell. Since the front section used direct drive, O- rings were not used. Instead, a larger aluminum disk of 1.125 inch diameter and 0.1875 inch width was used. It was attached to the motor shaft by two set screws tightened down against it. It was then attached to the front shell by two other screws.

Bearings. For each section to rotate independently, a total of five bearings were used; one for the front section, and two each for the mid and rear sections (Figure 2-3). The bearings were radial phenolic retainer open bearings with a width of 0.156 inch. Their outer diameter was 1.125 inches with an inner diameter of 0.875 inch (10:24). The three furthest rear bearings were placed on the shaft and the shaft notched so that the bearing would not move. The front two bearings were removable to allow for model assembly.

Sensors. To measure spin rate, internal reflective optical sensors were used in the mid and rear sections. The sensors consisted of a transmitter and receiver in a single housing (12:18). The mid section sensor was placed 0.3125 inch behind the mid section bearing while the rear section sensor was placed 0.094 inch in front of the rear section bearing (Figure 2-3). To trigger the sensor, a white line was painted in the interiors of the shells so that the sensor counted each revolution. The front section could not house a sensor but was instead synchronized with the rear section.

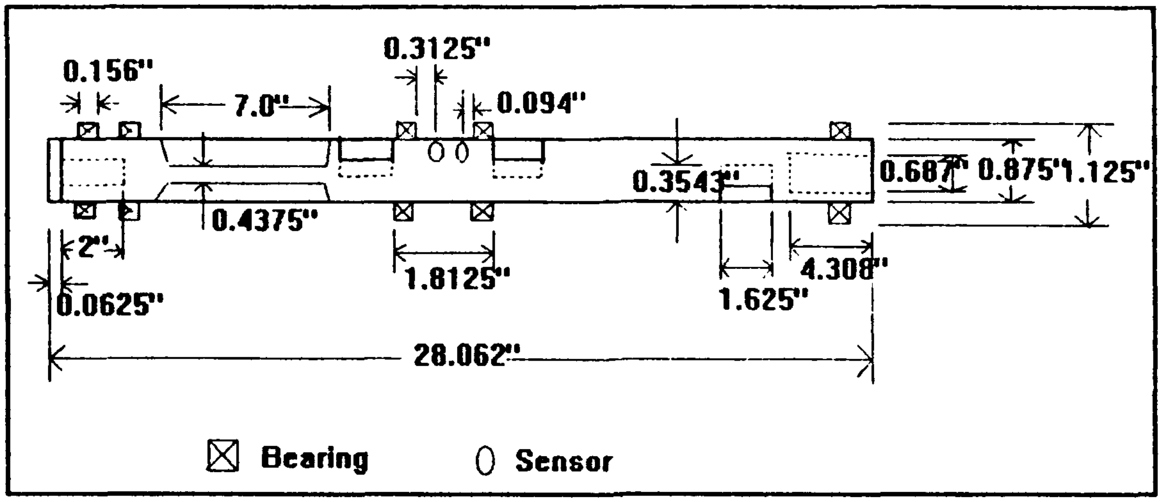

Figure 2-3. Aluminum Shaft Schematic

Instrumentation

Force Balance. The balance used was a 0.5 inch Mark II, six component strain-gage balance designed by Able Corp. (Figure 2-4) (17:3). Normal force and pitching moment were measured with two normal gages, N1 and N2, which were spaced 2.1 inches apart. The maximum total normal force allowed was 16 lb_f and a 16.8 in-lb_f for pitching moment. Yaw force and yaw moment were measured with the side gages, Y1 and Y2 which were 1.70 inches apart. The maximum total yaw force allowed was 10 lb_f with a 8.5 in-lb_f yaw moment maximum. For axial force, the gage, AX, was allowed to measure a maximum of 5 lb_f. The last gage, roll moment, RM, had a maximum of 2 in-lb_f. The accuracy of each gage was "+/- 0.25% of maximum load or +/- 0.5% of applied load when compared with the best straight line fit"(17:4). This meant normal force accuracy was +/- 0.04 lb_f, yaw force accuracy was +/_ 0.025 lb_f, and axial force accuracy was +/- 0.0125 lb_f.

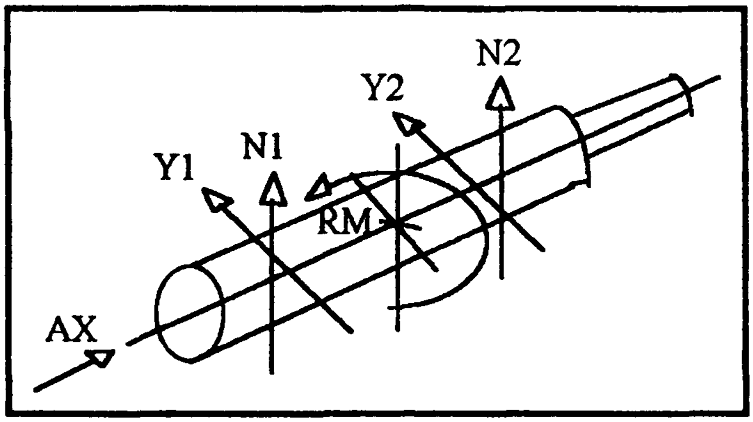

Figure 2-4. Force Balance Gage Orientation

Power Supplies. Three power supplies were used in the experiment. Two were used to power the four motors inside the model. A Hewlett-Packard 6205B Dual DC Power Supply was used to run the nose and rear sections, while a Hewlett-Packard 6236B Triple Output Power Supply was used to run the mid section. A Hewlett-Packard 6205C Dual DC Power Supply powered the optical sensors which measured the rotation rates of the mid and rear sections.

Multimeters. Three multimeters were used to measure/track the voltage needed to maintain a certain spin rate for each spinning section. The multimeters for the nose and rear sections were both Hewlett-Packard 3466A Digital multimeters while a Hewlett-Packard 3438A Digital multimeter was used for the mid section.

Counters/Strobe. Counters were used to set the rotation rates of the mid and rear sections. A Recal-Dana 1992 Nanosecond Universal Counter was used for the mid section, while a Hewlett-Packard 5316A Universal Counter was used for the rear section. A strobe was used to set the front section to the same spin rate as the rear section.

Facilities

AFIT 5 Ft Wind Tunnel. The AFIT 5 Ft wind tunnel was built in 1919 at the old McCook Field in Dayton, Ohio. It is a wooden circular tunnel that is an open circuit, continuous flow tunnel. It has a contraction ratio of 3.7 to 1 and a 5 ft closed test section. The top speed in the test section is 200 mph and is induced by two counter-rotating 12 ft diameter fans.

HP 3852B Acquisition Unit. This digital data acquisition unit took all readings from the test section except the spin rates of the sections and the atmospheric pressure which were operator entered into the computer. In this experiment, the following voltage readings were taken: the six balance gages (i.e. N1, N2, Y1, Y2, AX, and RM), angle of attack (alpha), yaw angle (beta), dynamic pressure (Q), free stream temperature, and the base pressure of the model.

Computer Acquisition Software. An integrated program runs all aspects of data collection, reduction and presentation. Table 2-1 shows the program menu and a description of each choice. It contains a library of subroutines which collect and reduce calibration, tare, and run data. Collection routines can be modified to allow for used defined inputs or programs such as collecting spin rates in this experiment. Reduced data can be presented in many forms, i.e., balance forces, body forces, body axis, stability axis, and wind axis. However, the reduction program was designed for standard aircraft coefficient reduction, which was a limitation for this experiment.

Table 2-1.

Computer Program Overview

Setup	....Writes the system configuration file
System Configuration	
Model	...Writes model parameters to a file
Tunnel	...Writes tunnel parameters to a file
Corrections	...Writes correction selections to a file
Boundary	...Writes variable limits to a file
System Calibration	
Gage	...Reduces rawdata to the calibration matrix
Pressure	...Writes voltages from the pressure transducers
Angle to Volts	...Writes voltages from the angle transducers
Bend	...Writes bend of sting vs. force
System Tares	
Average	...Averages tare rawdata files
Reduce to Slopes	...Reduces rawdata to tare slopes
Define Acquisition	...Writes run.def files which controls acquisition
Run Acquisition	...Selects and runs acquisition programs
Run Reduction	...Selects and runs reduction programs
Pickout	...Selects and presents reduced data
Graphrun	...Selects reduced data for graphing

III. THEORY

When a spinning missile is at some angle of attack relative to the free stream flow, a side force, known as a Magnus force, is generated . This force is named after the physicist, G. Magnus, who in 1852, first studied and measured this effect (8:84). Most research on Magnus effects assume that when a circular cylinder with a spin rate, p (rev/sec), is placed perpendicular in a uniform flow stream, V, a lift force develops (5:2, 13:345) (Figure 3-1):

$$L = \rho V \Gamma \quad \text{(per unit length)} \qquad (3\text{-}1)$$

where:

Γ = circulation

ρ = density of air

Put in kinematic terms, the lift force is the cross product of the circulation and the velocity (13:346).

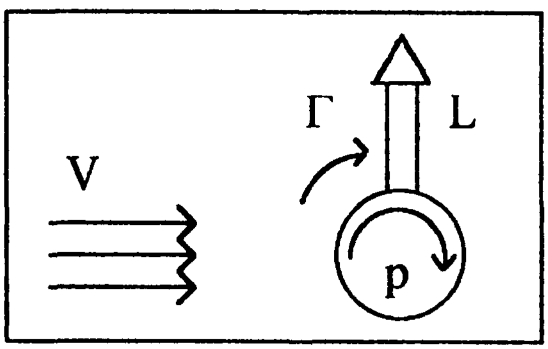

Figure 3-1 Lift on a Cylinder

Eq (3-1) is the Kutta-Joukowski Theorem which states

> "if there is a circulation Γ around an infinite cylinder of arbitrary cross section placed in a uniform stream V, the cylinder will experience a lift force L = ρ V Γ per unit length (7:358)."

This circulation, Γ, is defined as "the line integral of the velocity around any closed curve" symbolically shown as:

$$\Gamma \equiv \oint_c \bar{V} \bullet d\bar{r} \qquad (3\text{-}2)$$

where

$\bar{V}$ = velocity vector

$\bar{r}$ = vector radius from any fixed origin

c = any closed curve

When circulation is applied to a cylinder such as in Figure 3-2, it becomes (16:267-271):

$$\Gamma = \int_0^{2\pi} V r \, d\theta = 2\pi p r^2 \int_0^{2\pi} d\theta \qquad (3\text{-}3)$$

$$\Gamma = 4\pi^2 p r^2 \qquad (3\text{-}4)$$

where: p = spin rate (rev/sec)

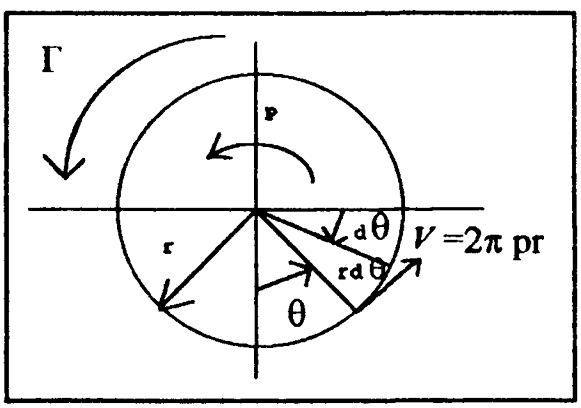

Figure 3-2. Circulation Defined

Using Eq (3-4) in Eq (3-1) yields a lift force of:

$$L = \rho V (4\pi^2 pr^2) \quad \text{(per unit length)} \tag{3-5}$$

However, for a spinning missile, Eq (3-5) is not appropriate. A spinning missile's Magnus force should be modeled by a rotating circular cylinder facing into the free stream velocity not perpendicular to it's line of symmetry.

Magnus Effects on a Single Cylinder

Magnus Force. A cylindrical missile has a coordinate system defined as in Figure 3-3. The X-axis is positive out the nose, the Y-axis is positive out the right side looking from the rear, and the Z-axis is positive toward the ground. The free stream velocity is defined in the x-axis of the inertial system. The spin rate, p, of the cylindrical missile is defined as rotating clockwise as seen from the rear of the cylinder. From the definition of circulation in Figure 3-2, the circulation of the cylindrical missile would be defined as $-\Gamma$ with the vector along the positive X-axis. In this configuration, any force generated due to spinning is defined as a Magnus force.

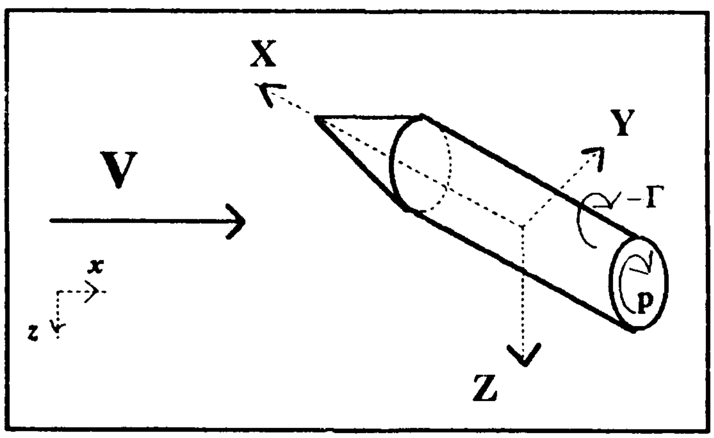

Figure 3-3. Body Axis Reference Frame

Generalizing to only a cylinder as in Figure 3-4, at zero angle of attack, the free stream velocity is along the negative X-axis of the cylinder's axis frame. In this situation, no force can be generated since the velocity and circulation vectors are both in the same axis and their cross product is zero.

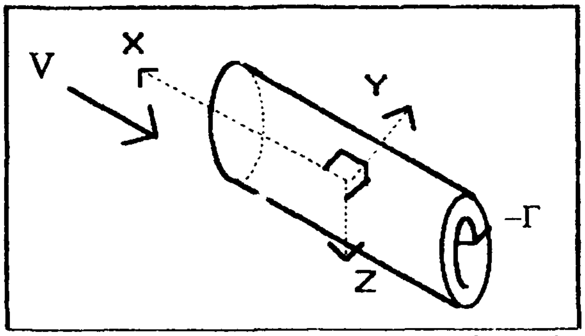

Figure 3-4. Cylinder at Zero Angle of Attack

Therefore, the only time a Magnus force is generated is when the cylinder is at some angle of attack, α. When the cylinder is at an angle of attack, the velocity vector has two components in the cylinder's body frame, i.e. $V \sin \alpha$ and $V \cos \alpha$. It is the normal velocity component, $V \sin \alpha$, that is perpendicular to the circulation vector and can generate a Magnus force, Y_p (Figure 3-5). The Magnus force generated is along the negative Y-axis.

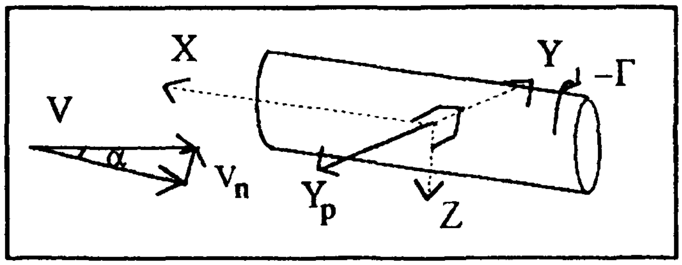

Figure 3-5. Cylinder at Angle of Attack, α

To define the Magnus force, Eq (3-5) is translated to the cylinder system by using the normal velocity, V sin α, instead of the free stream velocity V, and the circulation is defined as $-\Gamma$ instead of Γ. This leads to the definition of the Magnus force, Y_p, for a single spinning cylinder as:

$$Y_p = -\rho V \sin\alpha\, \Gamma \tag{3-6}$$

then substituting Eq (3-4) into Eq (3-6) leads to:

$$Y_p = \rho V \sin\alpha (-4\pi^2 pr^2) \quad \text{(per unit length)} \tag{3-7}$$

For a cylinder of length, l:

$$Y_p = \rho V \sin\alpha (-4\pi^2 pr^2)\, l \tag{3-8}$$

If dynamic pressure is defined as $q = \frac{1}{2}\rho V^2$, the longitudinal cross sectional area of the cylinder is defined as $S_l = 2rl$, velocity ratio is defined as VR = $(\frac{2\pi pr}{V})$, and for small angles of attack, sin $\alpha = \alpha$, then Eq (3-8) can be rewritten as:

$$Y_p = -2\pi q S_l\, VR\alpha \tag{3-9}$$

To put it in aeronautical coefficient form,

$$C_{Y_p} = \frac{Y_p}{q\, S_l\, VR\alpha} = -2\pi \tag{3-10}$$

Magnus Moment. The Magnus moment is the Magnus force multiplied by the distance from the cg to the Magnus force center of pressure which is assumed to be in front of the cg. (13:346). This distance is denoted by x. Taking the cross product of the distance, x, which is along the positive X-axis, and the Magnus force, $-Y_p$, the Magnus moment is along the negative Z-axis or:

$$n_p = Y_p\, x \tag{3-11}$$

The coefficient form of the Magnus moment is the same as in Eq (3-10), but with the addition of the cylinder length.

$$C_{n_p} = \frac{n_p}{q\, S_l\, \alpha\, l\, VR} = -2\pi x \tag{3-12}$$

<u>Magnus Effects with Partially Spinning Sections</u>

<u>Magnus Forces.</u> For a cylinder which has two sections that rotate at the same speed as the single cylinder, each section's Magnus force would be the same as in Eq (3-8) except that the length, l, would be the length of the spinning section only (Figure 3-6) denoted by $(\ )_f$ or $(\ )_r$ for the front or rear section, respectively. The Magnus force for each section would be a percentage of the total length:

$$Y_{p_f} = \rho V \sin\alpha \,(-4\pi^2 p r^2\, l_f) = \left(\frac{l_f}{l}\right) Y_p \tag{3-13}$$

$$Y_{p_r} = \rho V \sin\alpha \,(-4\pi^2 p r^2\, l_r) = \left(\frac{l_r}{l}\right) Y_p \tag{3-14}$$

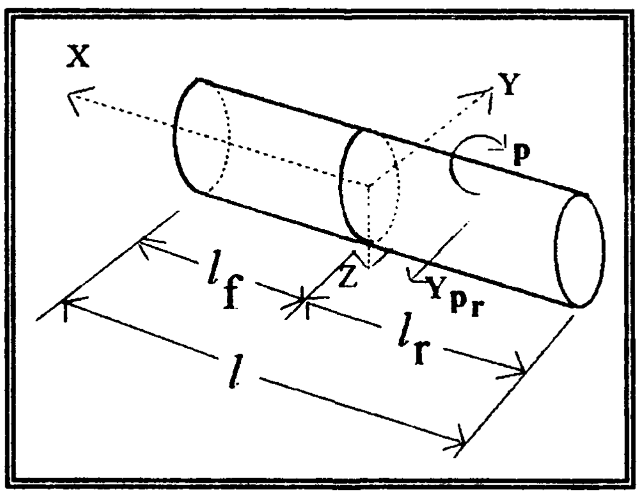

Figure 3-6. Rear Section Spinning Only

However, their coefficients would be based on the total length or:

$$C_{Y_{pf}} = \frac{Y_{p_f}}{qS_l \ \alpha \ VR} \tag{3-15}$$

$$C_{Y_{pr}} = \frac{Y_{p_r}}{qS_l \ \alpha \ VR} \tag{3-16}$$

Each coefficient for a partially spinning cylinder, would be a percentage of a single cylinder based on the same total length, l, or:

$$C_{Y_{pf}} = (\frac{l_f}{l})\frac{Y_p}{qS_l \ \alpha \ VR} = -2\pi(\frac{l_f}{l}) \tag{3-17}$$

$$C_{Y_{pr}} = (\frac{l_r}{l})\frac{Y_p}{qS_l \ \alpha \ VR} = -2\pi(\frac{l_r}{l}) \tag{3-18}$$

<u>Magnus Moments.</u> For the Magnus moments, each would be based on half their respective lengths, assuming that the cg. of the total cylinder is at the point where the two sections join and that the center of pressure for a section is at the mid point of each section or:

$$n_{p_f} = \frac{Y_{p_f} \ l_f}{2} = \frac{Y_p \ l_f^2}{2l} \tag{3-19}$$

$$n_{p_r} = -\frac{Y_{p_r} \ l_r}{2} = -\frac{Y_p \ l_r^2}{2l} \tag{3-20}$$

The front section moment would be in the negative Z direction while the rear section moment would be in the positive Z direction . The Magnus moment coefficients are determined the same as in Eq (3-12) or:

$$C_{n_{pf}} = \frac{n_{p_f}}{q \ S_l \ \alpha \, l \ VR} = -\pi(\frac{l_f^2}{l^2}) \tag{3-21}$$

$$C_{n_{pr}} = \frac{n_{p_r}}{q\, S_l\, \alpha\, l\, VR} = \pi(\frac{l_r^2}{l^2}) \qquad (3\text{-}22)$$

Magnus Effects with Differentially Spinning Sections

Magnus Force. For a cylinder that has two sections rotating at different rates, the forces of each can be calculated and then added together to obtain the total Magnus force (Figure 3-7), if it is assumed that there is no influence of the front spinning section on the rear spinning section. The Magnus force of the rear section with a spin rate, p, would be as shown in Eq (3-14). For a cylinder with the front section spinning in the same direction as the rear but at an increased spin rate of (p+Δp), the equation would be similar to Eq (3-13) or:

$$Y_{pf} = \rho V \sin\alpha \left[-4\pi^2 (p + \Delta p) r^2 l_f\right] \qquad (3\text{-}23)$$

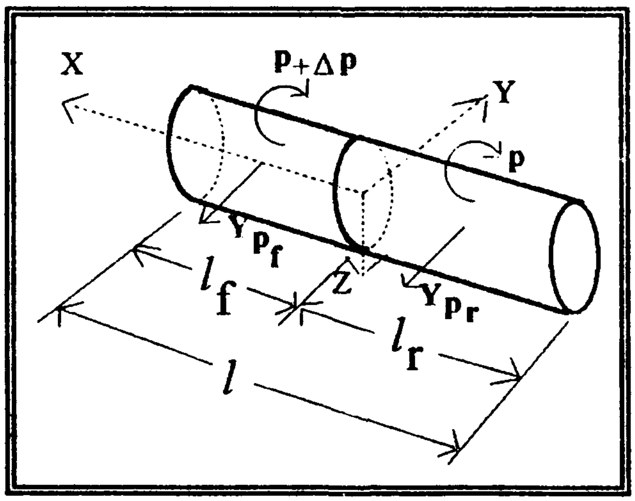

Figure 3-7. Both Sections Spinning

When the two forces are added together, the resulting Magnus force, $Y_{(p+\Delta p)}$ is equal to the force for a single spinning cylinder of length l plus an additional force proportional to the percentage of the front section to the total length for the delta spin rate:

$$Y_{(p+\Delta p)} = \rho V \sin\alpha[-4\pi^2 pr^2(l_f + l_r)] + \rho V \sin\alpha(-4\pi^2 \Delta p r^2 l_f) \quad (3\text{-}24)$$

$$= Y_p + \Delta Y_{pf} = Y_p\,(1 + \frac{\Delta p l_f}{p l}) \quad (3\text{-}25)$$

If the front section were spun in the opposite direction at an increased spin rate of $-(p + \Delta p)$, the Magnus force, $Y_{-(p+\Delta p)}$ would be:

$$Y_{-(p+\Delta p)} = \rho V \sin\alpha\left[-4\pi^2 pr^2(l_r - l_f)\right] + \rho V \sin\alpha\left[-4\pi^2(-\Delta p)r^2 l_f\right] \quad (3\text{-}26)$$

$$= Y_{p(l_r - l_f)} - \Delta Y_{pf} = Y_p(\frac{l_r - l_f}{l} - \frac{\Delta p l_f}{p l}) \quad (3\text{-}27)$$

In Figure 3-8, three cases are shown: A) All sections spinning at the same speed; B) the mid section spinning faster and in the same direction; C) the mid section spinning faster but in the opposite direction.

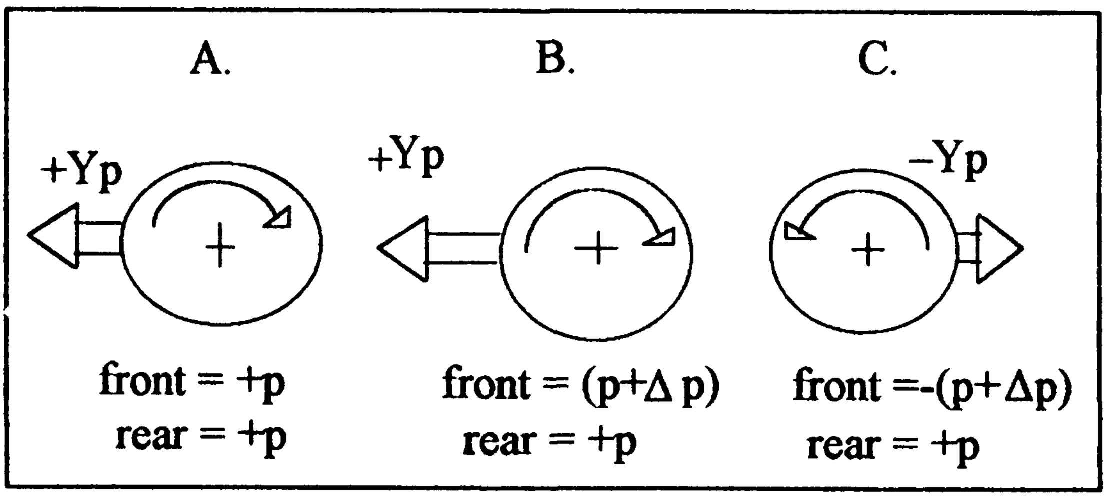

Figure 3-8. Differentially Rotating Sections

Note that for case C, the total Magnus force can be either positive or negative depending on the spin rate, p, and Δp chosen. Each of the forces would nondimensionalize the same as in Eq (3-10) giving:

$$C_{Y_{(p+\Delta p)}} = -2\pi(1+\frac{\Delta p l_f}{p l}) \tag{3-28}$$

$$C_{Y_{-(p+\Delta p)}} = -2\pi(\frac{l_r - l_f}{l} - \frac{\Delta p l_f}{p l}) \tag{3-29}$$

<u>Magnus Moments</u>. To calculate the Magnus moments when the front section is spinning at an increased spin rate of (p+Δp), it is assumed that the cg. of the cylinder is at the meeting point of the two sections and that the center of pressure of each section is at the mid point of that section. The moment arm is in the positive X direction for the front section while for the rear section it is in the negative X direction. When crossed with the Magnus force vector, the total moment is in the negative Z direction. The moment, $n_{(p+\Delta p)}$, is equal to:

$$\begin{aligned} n_{(p+\Delta p)} &= [Y_{p_f}(\tfrac{1}{2}l_f) + \Delta Y_{p_f}(\tfrac{1}{2}l_f)] - Y_{p_r}(\tfrac{1}{2}l_r) \\ &= \tfrac{1}{2}\frac{Y_p}{l}(l_f^2 - l_r^2 + \frac{\Delta p l_f^2}{p}) \end{aligned} \tag{3-30}$$

A moment in the negative Z direction is defined as a positive Magnus moment. For the cases where the front section is smaller than the rear section, the moment generated would become progressively less positive with the possibility of becoming negative.

When the front section is spinning in the opposite direction at -(p+Δp), the moment, $n_{-(p+\Delta p)}$, would equal:

$$n_{-(p+\Delta p)} = (-Y_{p_f} - \Delta Y_{p_f})(\tfrac{1}{2} l_f) - (Y_{p_r})(\tfrac{1}{2} l_r)$$
$$= -\frac{1}{2}\frac{Y_p}{l}(l_f^2 + l_r^2 + \frac{\Delta p l_f^2}{p}) \qquad (3\text{-}31)$$

For cases where the front section is smaller than the rear section, the moment would be progressively less negative but not less than the amount for a single spinning cylinder. To obtain coefficients, the Eqs (3-30 and 3-31) and Eq (3-12) are used:

$$C_{n(p+\Delta p)} = -\pi(\frac{l_f^2 - l_r^2}{l^2} + \frac{\Delta p l_f^2}{p l^2}) \qquad (3\text{-}32)$$

$$C_{n-(p+\Delta p)} = \pi(\frac{l_f^2 + l_r^2}{l^2} + \frac{\Delta p l_f^2}{p l^2}) \qquad (3\text{-}33)$$

Model Predictions.

Since this missile has a pointed nose cone in addition to a cylinder body, the total length of the missile does not take this nose cone shape into account. Some suggest that an effective length be used. Effective length, l_{eff}, can be defined as half the nose length, l_n, plus the body length, l_b, or (5:4):

$$l_{eff} = 1/2\, l_n + l_b \qquad (3\text{-}34)$$

For the model in this experiment, the effective length, l_{eff}, equaled 34.55 inches. The length of the mid section was 35.82% of the total effective length and the front/rear combination was 64.18% of the total effective length.

Magnus Forces. By using the equations determined above, predicted Magnus effects can be determined for the model. For the mid section spinning only, the $C_{Y_{pf}}$ would equal (0.3582 C_{Y_p}) or (-0.7164π) from Eq (3-17). For the front/rear sections

spinning only, the $C_{Y_{pr}}$ would equal ($0.6418\ C_{Y_p}$) or (-1.2836π) from Eq (3-18). The $C_{Y(p+\Delta p)}$ for the mid section spinning at a $+\Delta p$, would equal: $-2\pi(1+0.3582\frac{\Delta p}{p})$ from Eq(3-28). When the mid section is spinning in the opposite direction at $-(p+\Delta p)$, the $C_{Y-(p+\Delta p)}$ would equal: $-2\pi(0.2836-0.3482\frac{\Delta p}{p})$ from Eq (3-29). Figure 3-9 shows the Magnus force versus angle of attack, α, graphically, for all five cases examined: mid section spinning only, front/rear sections spinning only, all sections spinning at the same speed, the mid section spinning faster and in the same direction, and the mid section spinning faster but in the opposite direction; based on a spin rate, p = 21 rps, a Δp = 10 rps. For this spin rate, all Magnus forces should have a negative magnitude.

Magnus Moments. The Magnus moment coefficients can also be predicted. When the moment is taken about the mid point of the two sections and the center of pressures are at the mid point of each section, the moment for both sections spinning in the same direction and at the same spin rate, p, is zero. For the mid section spinning only, C_{npf} equals (-0.1283π) from Eq (3-21). For the front/rear sections spinning only, C_{npr} would equals (0.4119π) from Eq (3-22). For the case of the mid section spinning a +10 rps faster in the same direction, $C_{n(p+\Delta p)}$ would equal $[-\pi(-0.2836+0.1283\frac{\Delta p}{p})]$ from Eq (3-32). When the mid section is spinning at +10 rps faster but in the opposite direction, $n_{-(p+\Delta p)}$ would equal $[\pi(0.5402+0.1283\frac{\Delta p}{p})]$. Using the same spin rates as used in Figure 3-9, Figure 3-10 shows the predicted Magnus moments.

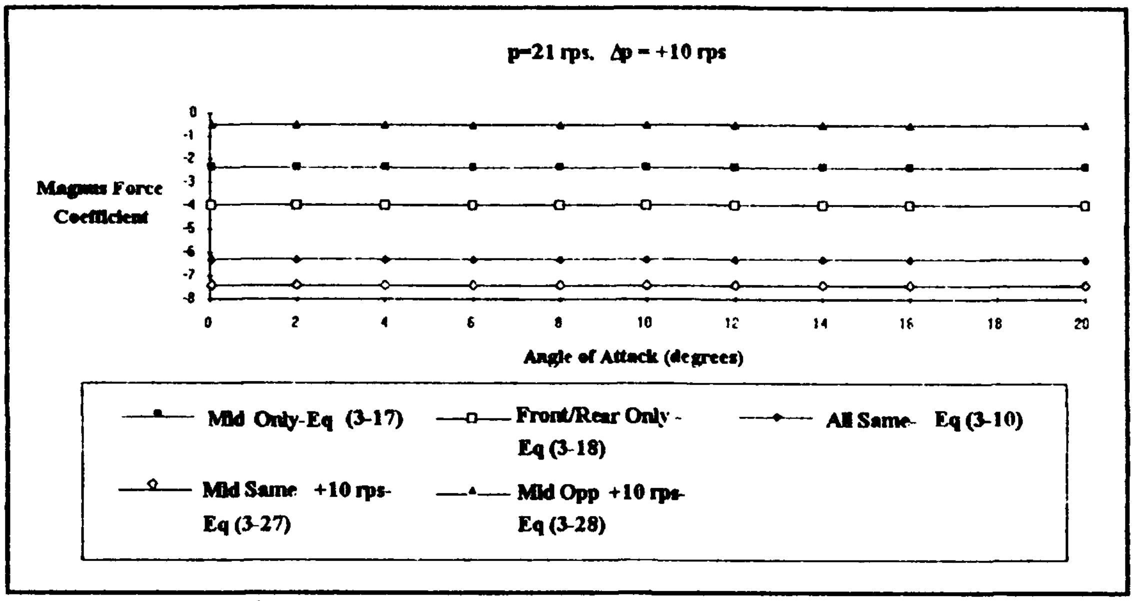

Figure 3-9. Predictions for Magnus Force Coefficients

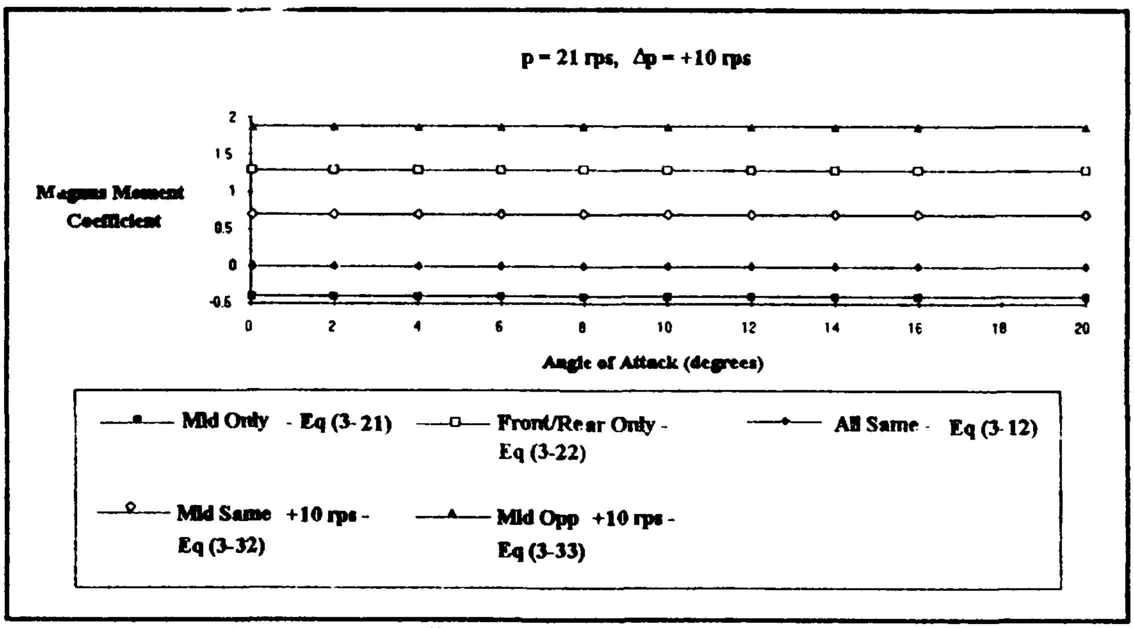

Figure 3-10. Predictions for Magnus Moment Coefficients

Single Cylinder Research. Only limited research on Magnus effects has been conducted. Most of the research has been for the infinite spinning cylinder case as shown in Figure 3-1 (5:9), and no research was found in the area of differentially rotating cylinders. Eq (3-10), the basis for the predictions in Figures 3-9 and 3-10, was developed based on 2-D flow theory, not 3-D flow as in the case of a spinning missile at an angle of attack. In reality, Magnus effects are caused by changes in the boundary layer and vortex patterns and their magnitude and direction are dependent on; spin rate, angle of attack, velocity ratio and Reynolds number. At low angle of attack and laminar flow, the vortices stay within the boundary layer which causes a thickening of the boundary layer in the direction of the spin (Figure 3-11). This effectively creates an asymmetric body shape that generates a side force in the negative Y direction. At higher angles of attack, the laminar flow has separated with two symmetric vortices (Figure 3-12a). With spinning, the separated flow shifts in the direction of spin which also generates a force in the negative Y direction (Figure 3-12b) (15:198). The magnitude and direction of the Magnus force is also dependent on the velocity ratio, VR which is defined as $(\frac{2\pi pr}{V})$. At low angles of attack, the larger the velocity ratio, the larger the force becomes and the closer the transition region moves toward the nose (Figure 3-13) (5: 20). At high angles of attack, as the velocity ratio grows larger, the magnitude becomes smaller and smaller until it switches direction and begins growing larger again in the new direction. For this experiment, the velocity ratio was under 0.15 for all test cases. And, though not explicitly stated in Jacobsen, a velocity ratio of this size and smaller is considered small. This means that for any angle of attack, the Magnus force should be small and in the negative Y direction.

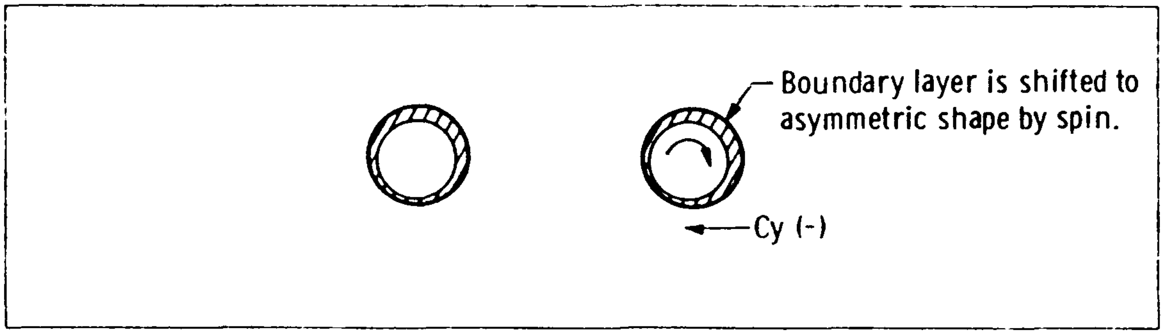

Figure 3-11 Low Angle of Attack Disturbances (15:198)

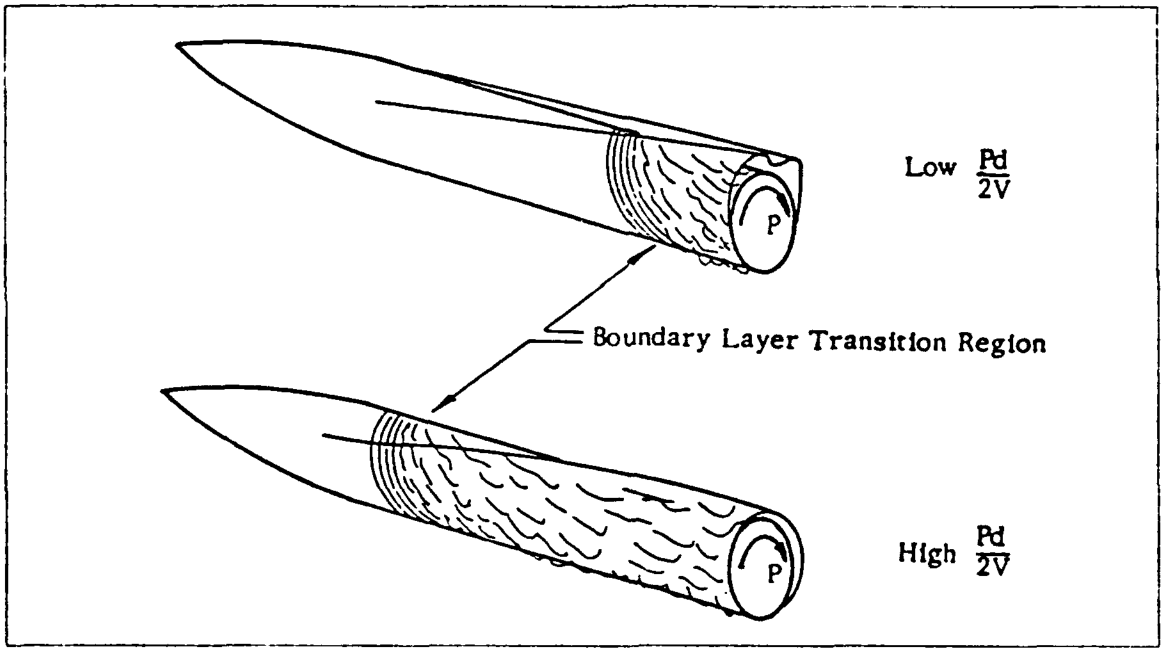

Figure 3-12. Low Angle of Attack Transition Region (5:20)

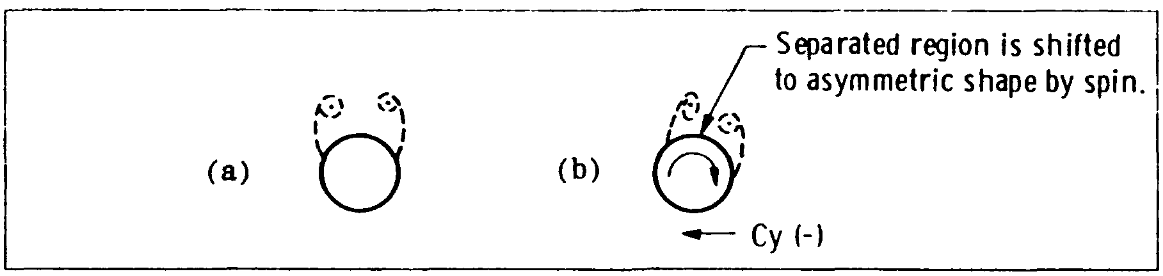

Figure 3-13. High Angle of Attack Disturbances (15:198)

IV. TEST SET-UP AND PROCEDURES

In any wind tunnel experiment, there are preliminary tests and checkouts that must be done before starting the test matrix in order to insure that the data obtained is accurate and reliable. In general, the balance is calibrated, a tare run made and checked out. Once the preliminary tests are completed, the test runs begin.

Calibration

The force balance was calibrated to ensure that all gages performed accurately and correctly. Each gage was calibrated in the positive and negative direction. Both are necessary in order to create the calibration matrix which was used to eliminate interaction between the gages when reducing the data. To calibrate, the calibration body was placed on the balance with a rod hanging from it. A weight was placed on the rod and the deviation from zero degrees was measured with an inclinometer in minutes. Then the sting/balance was raised back to zero and the data point taken. This procedure was repeated throughout each gage's range. The entire range of each gage was calibrated, though more data points were taken at the low end to ensure greater accuracy in that region. From the data points, the weight vs. voltage curve (Figure 4-1), the sting bend vs. angle of attack curve, and each gage's linear correlation were all calculated. The linear correlation for each gage was determined from the curves shown in Figure 4-1. All gages had excellent correlations.

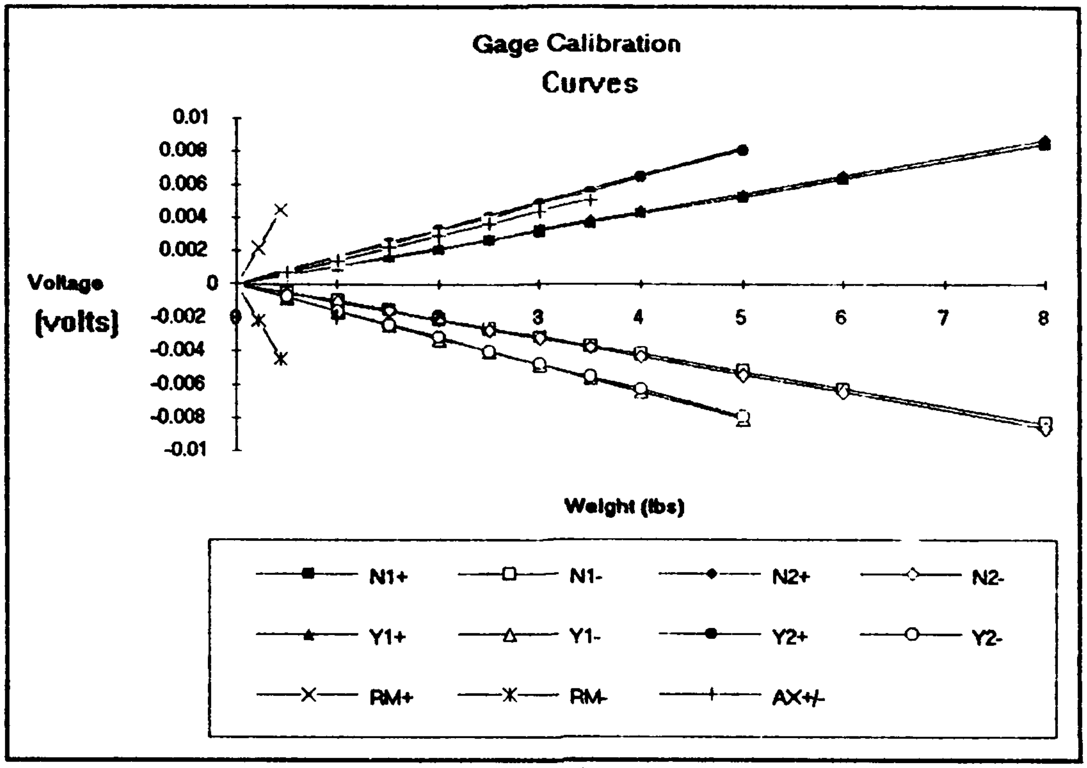

Figure 4-1. Gage Calibration Curves

Table 4-1

Gage Correlations

	N1	N2	Y1	Y2	RM	AX+/-
Positive	.99999	.99997	.99994	.99996	1.0	.99967
Negative	.99996	.99998	.99998	.99993	1.0	

Tare Run

With the model on the balance, an angle of attack sweep from 0 - 16 degrees by 2 degree increments was done with no air on. With this data, the reduction program found the weight of the model and the distance from the electrical center of the balance to the cg.

for each axis. To make sure that this information was correct, a test run with no air on was done. This was an α sweep from 0 - 16 degrees by 2 degree increments up and 4 degree increments down. The run was reduced using the tare information. The forces and moments were evaluated to see how accurately the tare was. If the tare was accurate and the data extremely repeatable, all the forces would be zero at every angle of attack. This, however, was not the case (and never is). In order to have the cleanest data possible, the tare numbers were adjusted until the best solution was reached so that the yaw force would be most accurate. The adjusted weight was determined to be 1.90 lb_f and the distances to the cg. were 0.5875 ft in the X direction, -0.003843 ft in the Y direction, and 0.035077 ft in the Z direction from the electrical center. Table 4-2 shows the error of the tare. For all angles, less than 0.014 lb_f remained in the yaw force, less than -0.018 lb_f in the normal force, and less than -0.056 lb_f in the axial force. For normal and yaw forces, these numbers were within theerror of the balance, i.e., +/-0.04 lb_f for the normal force and +/-0.025 lb_f for the yaw force. Axial force error, however, was more than four times the error of the balance, i.e., +/-0.0125 lb_f, but this was deemed acceptable for this experiment.

Table 4-2.

Tare Accuracy

Alpha	Beta	NormFor	YawFor	AxialFor	PitchMom	YawMom	RollMom
0.1	1.07	-0.0153	0.0117	0.001	0.0014	0.0003	0.0003
2	1.1	-0.0014	0.0012	-0.0134	0.0017	0.0001	0.0001
3.99	1.1	-0.0039	0.0038	-0.0146	0.0005	0.0003	0.0001
6.1	1.07	-0.0177	0.014	-0.0275	0.0022	0.0011	0.0001
8.02	1.14	-0.0064	0.0019	-0.0331	0.0028	0.0016	-0.0001
10.08	1.14	0.0096	0.0026	-0.042	0.0032	0.0021	-0.0002
12.09	1.1	0.007	-0.0002	-0.0456	0.0028	0.0017	0.0002
14.06	1.07	0.0093	0.0068	-0.0439	0.0014	0.0024	0.0003
16.05	1.07	0.0055	0.0036	-0.056	0.0021	0.0027	0.0002

Test Runs

Preliminary testing was done to determine the wind tunnel speeds that caused the least model vibration. Tunnel speeds of 114 ft/s and 162 ft/s were decided on. By taking the lowest spin rate which did not vibrate the model, and the lowest tunnel speed, a velocity ratio of 0.042 was found. The rest of the test matrix was determined by picking velocity ratios of 0.07 and 0.1 and determining the spin rates needed to obtain them (Table 4-3).

Table 4-3.

Test Matrix

	VR = 0.04	VR = 0.07	VR = 0.10
V = 114 ft/s	p = 15 rps	p = 23 rps	p = 33.5 rps
V = 162 ft/s	p = 21 rps	p = 33 rps	p = 47.5 rps

Within each of the six above test configurations, five different spin cases were done. These were: a) mid section spinning only; b) front/rear sections spinning only; c) all sections spinning at the same speed; d) all sections spinning with the mid section at 10 rps faster than the front/rear in the same direction; and e) all sections spinning with the mid section at 10 rps faster than the front/rear in the opposite direction. From these cases, it was hoped that the contributions of each section, and the influence of the mid section on the front/rear section could be determined.

Test Set-Up

The following procedure was used when a test run was accomplished. The flow of data acquisition and the test set-up are shown in Figure 4-2. 1) A barometer reading was taken and manually input into the Z-248 computer; 2) A reading was taken at zero angle of attack and the air off; 3) The tunnel air was set to the desired velocity and the spin rate of the section(s) set by counter and strobe readings; 4) Once the tunnel reached the correct velocity, an alpha sweep from 0 - 16 degrees of attack at 2 degree increments up and 4 degree increments down was begun; 5) a data point was taken at each increment by the HP 3852B Acquisition unit and the operator read the spin rate(s) off the counters and input them manually into the Z-248 computer; 6) after the full alpha sweep, the tunnel air was turned off.

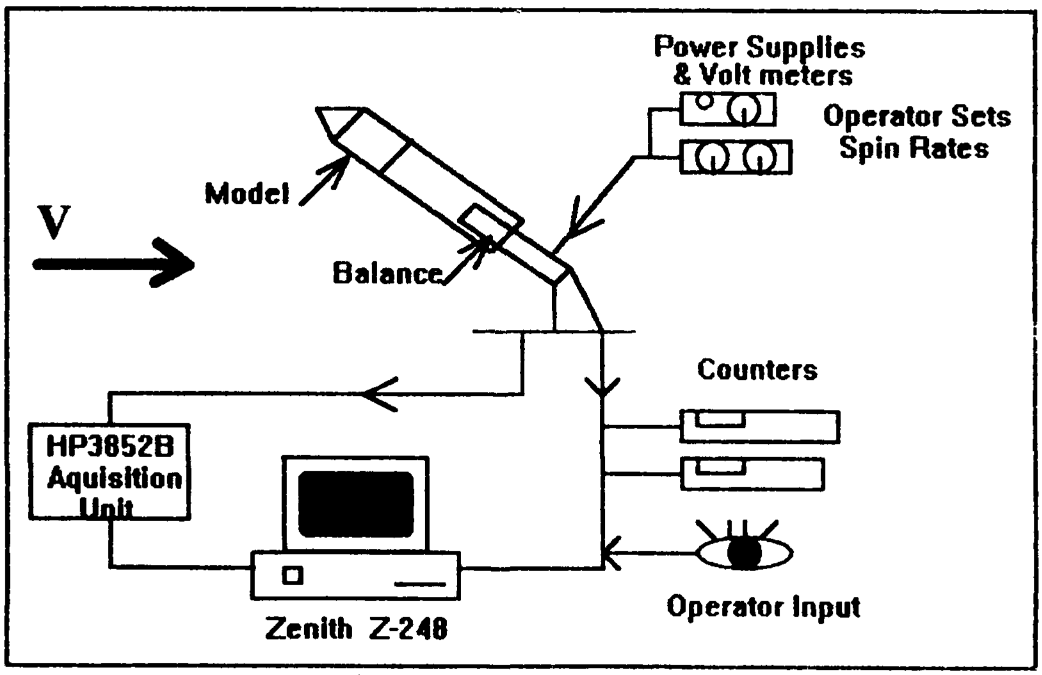

Figure 4-2. Test Set-Up

Once the test matrix was complete and the results reviewed, eight test runs were repeated in order to test repeatability of the data. Repeatability was defined as good when each of the side force gages, Y1 and Y2, were within 0.3 lb_f for a point within the alpha sweep. Four repeats were test runs that did not have good repeatability within the alpha sweep and four were test runs which did have good repeatability. Seven of the eight repeats provided as good or better data. Examples of good and poor repeatability for the side force gages are shown in Figures 4-3 and 4-4, while Figures 4-5 and 4-6 show the repeatability of the normal force gages . In Figure 4-3, each side force gage had good repeatability, but the total side force, Y1+Y2, had variation. In Figure 4-6, the normal gage repeatability was good even though the side force gage repeatability for the same test run was poor as seen in Figure 4-4.

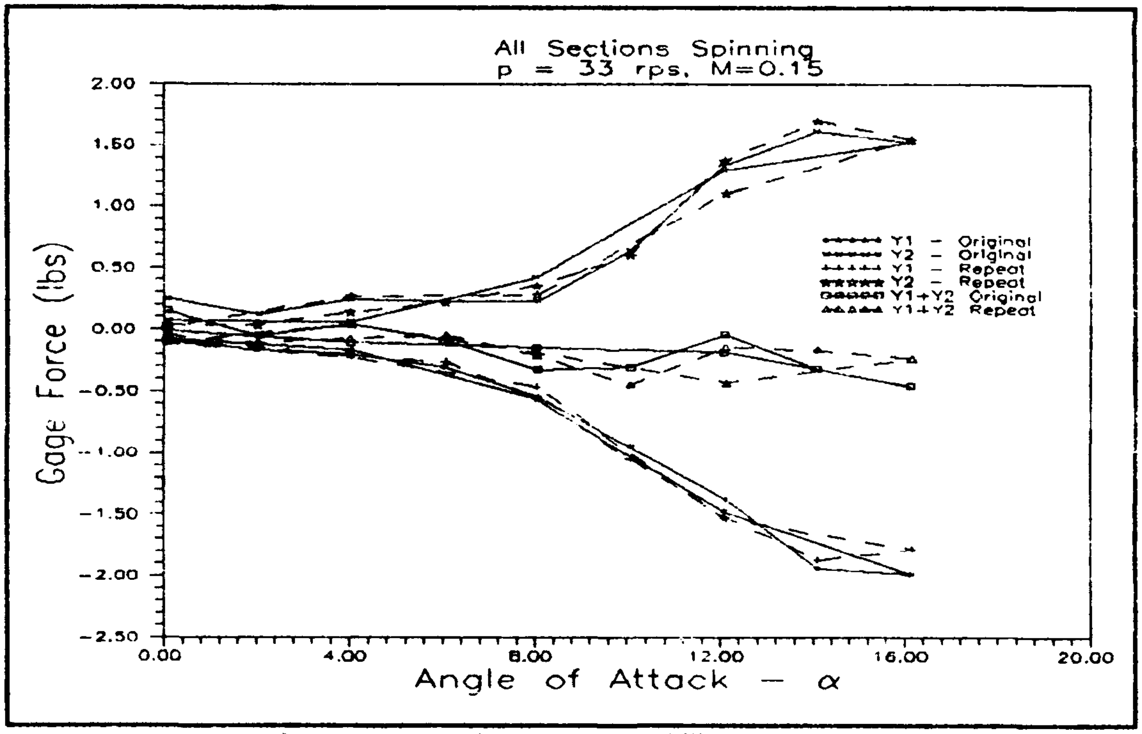

Figure 4-3. Good Gage Repeatability - Yaw Force

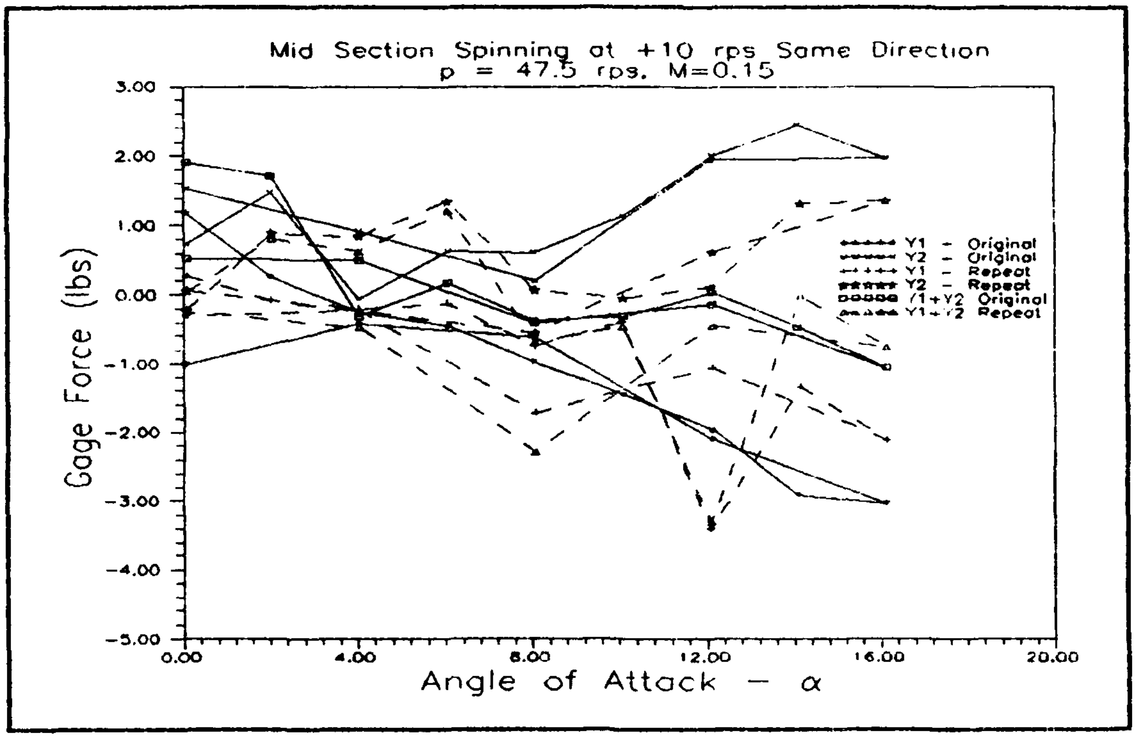

Figure 4-4. Poor Gage Repeatability - Yaw Force

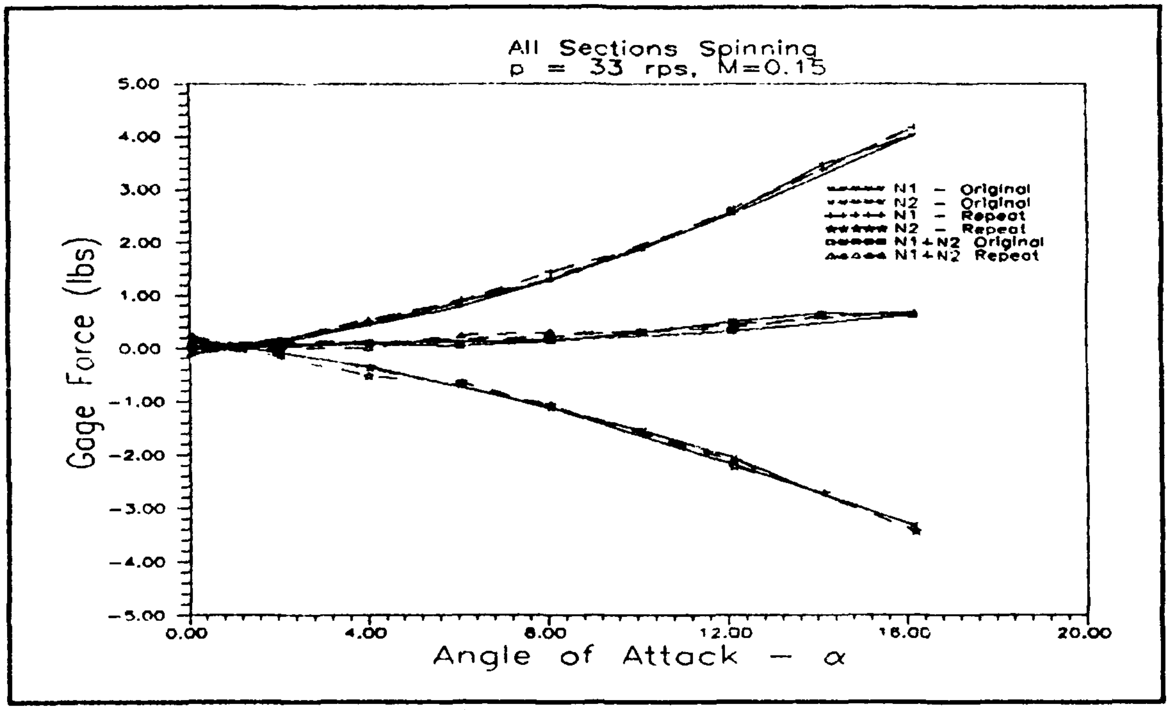

Figure 4-5. Good Gage Repeatability - Normal Force

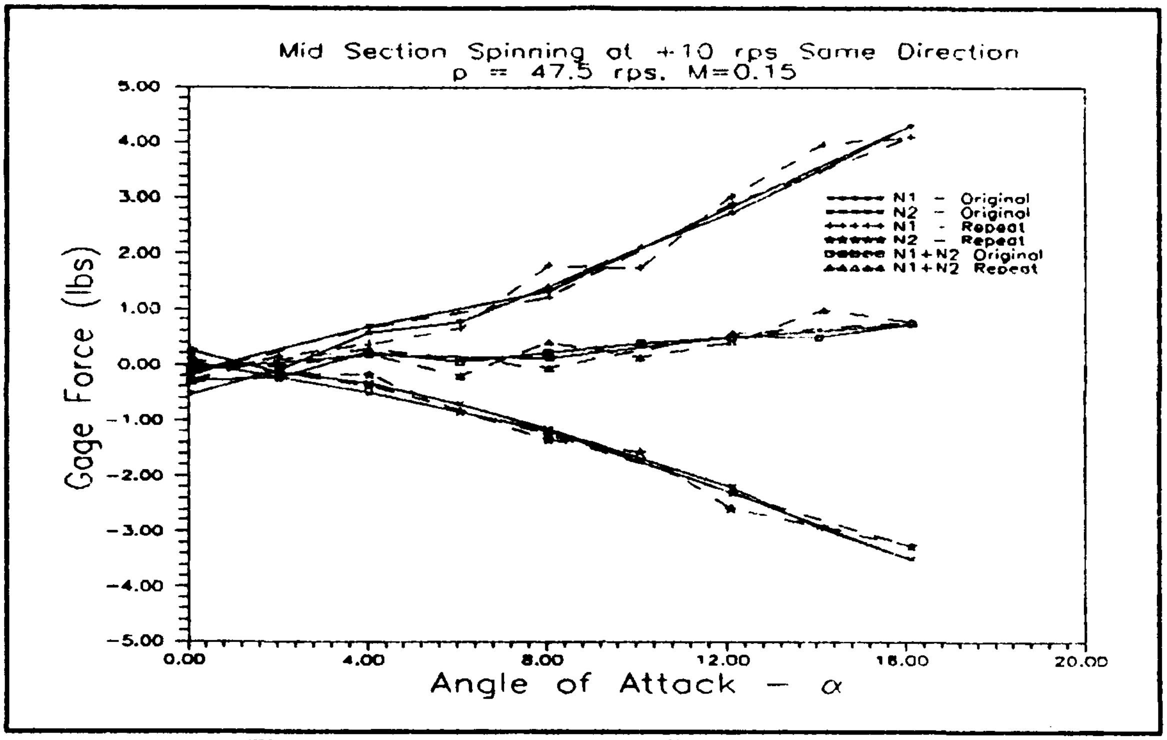

Figure 4-6. Poor Gage Repeatability - Normal Force

V. DATA REDUCTION

Wind Tunnel Corrections

When doing experiments in a wind tunnel, there are a number of corrections that need to be made to the data in order to take out the effects that the wind tunnel itself may impart to the data. In this experiment, three were applied. They were: a dynamic pressure skew factor, a solid blockage correction to the dynamic pressure, and a buoyancy correction to the Axial coefficient. A wake blockage correction to dynamic pressure was not included nor was a base pressure correction to the axial coefficient. Not enough information was found to accurately calculate these factors.

Skew factor. This factor accounts for the difference between where the dynamic pressure is measured in the tunnel and the dynamic pressure in the test section (11:142). The factor for this tunnel is 1.019 or:

$$Q_{actual} = Q_{measured} * 1.019 \tag{5-1}$$

Solid Blockage. By placing a model in the tunnel, the tunnel area where air can flow is reduced. From Bernoulli's equation and the continuity equation, the velocity flowing over the model increases. This increase is considered constant over the model and is called "solid blockage". It is calculated based on the model volume and tunnel area (11:353,364-6) or:

$$\varepsilon_{sb} = \frac{K(\text{model volume})}{C^{3/2}} \tag{5-2}$$

$$= 0.00032$$

where:

K = the body shape factor (0.96 for a body of revolution)

C = the tunnel test section area (19.635 sq. ft for this tunnel)

This leads to a new dynamic pressure equal to:

$$q = q_{calc} * (1 + \varepsilon_{sb})^{\frac{1}{2}} \tag{5-3}$$

Buoyancy. This factor accounts for the variation in static pressure due to boundary layer increase as the flow moves downstream. The boundary layer increase decreases the pressure along the test section creating a negative pressure gradient. This pressure change is in effect, making the tunnel section smaller downstream which causes the streamlines to squeeze together and increases the drag on the model. This drag increment is defined as:

$$\Delta C_{AB} = -\left(\frac{dp}{dl}\right)\left(\frac{\text{body volume}}{qS_r}\right) \tag{5-4}$$

$$= \left(\frac{0.8629}{q}\right)$$

where:

$\left(\frac{dp}{dl}\right)$ = slope of longitudinal static pressure curve

This coefficient increment is subtracted from the axial force coefficient (11:350-3, 362-4).

Magnus Effects

Magnus Force. Though the wind tunnel acquisition program reduced the data to force and moment coefficients, it used the standard aircraft nondimensionalization, q S_r, where q is the corrected dynamic pressure and S_r is the cross sectional area. This was not an appropriate way to nondimensionalize the Magnus force coefficient, since it was also a function of the spin rate, p and normal velocity, V sin α. Instead, the nondimensionalization of Eq (3-10) was used:

$$C_{Y_p} = \frac{Y_p}{q\, S_l \left(\frac{2\pi \mathrm{pr}}{V}\right) \alpha}$$

By using these parameters, the velocity ratio, the model length, and the normal component of the free stream velocity are taken into account. However, Eq (3-10) is for the case of a cylinder, not a missile. To apply the equation to this experiment, it must be modified to:

$$C_{Y_{pc}} = \frac{Y_{pc}}{q\, S_{l_{eff}} \left(\frac{2\pi \mathrm{p_{eff} r}}{V}\right) \alpha} \qquad (5\text{-}5)$$

where:

$$S_{l_{eff}} = 2\mathrm{r} l_{eff}$$

$$\mathrm{p_{eff}} = 0.6418\left(\frac{\mathrm{p_f} + \mathrm{p_r}}{2}\right) + 0.3582(\mathrm{p_m})$$

$$Y_{pc} = Y_p - N_s$$

This equation now takes into account the nose cone of the missile and the variations in spin rates due to the differential as well as the differences in spin rates between the front and

rear sections at angles of attack. However, by using the angle of attack, α, in the denominator, the coefficient tends to fluctuate greatly at small angles ($\alpha < 4$ degrees), but at higher angles, the data tended to collapse. Therefore, this variation at small angles was deemed acceptable.

The measured yaw force which should have only contained the Magnus force in this experiment, did, in reality, contain an additional yaw force due to a constant yaw angle, β, of 1.10 +/-0.05 degrees. This yaw force, N_β, was also in the negative Y direction and in effect added to the Magnus force. If not subtracted out, the Magnus force appeared larger than it actually was. From the geometry in Figure 5-1, this force,was equal to (9:966):

$$N_s = N_0 \sin\varepsilon \qquad (5\text{-}6)$$

where:

N_0 = the normal force without spinning

$$\sin\varepsilon = \frac{\tan\beta}{\sin\alpha}$$

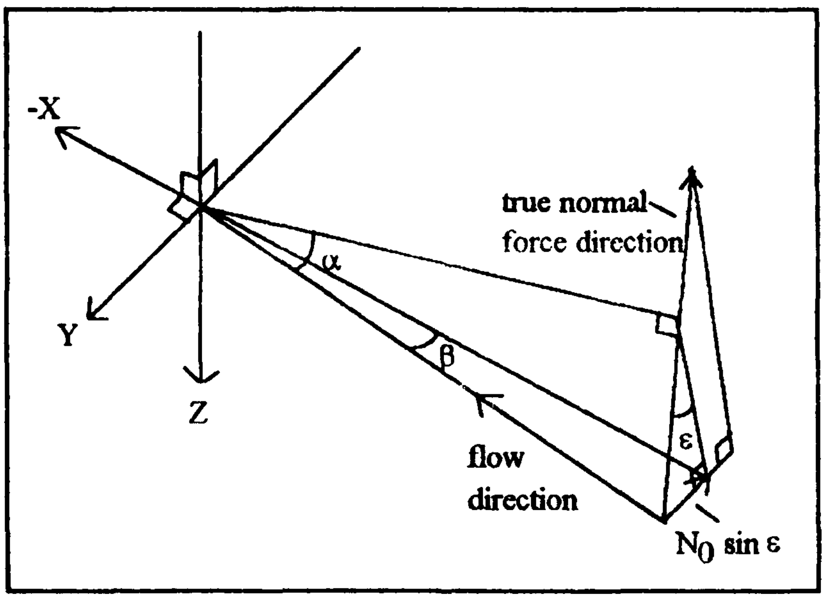

Figure 5-1. Geometry of Induced Beta Yaw Force (9:966)

This force was calculated for each angle of attack and subtracted out of the measured yaw force to give a corrected yaw force, Y_{pc}. Table 5-1 shows this beta induced yaw force for the two wind tunnel test velocities.

Table 5-1.

Beta Induced Yaw Forces (lb_f)

alpha	Ns-V=120	Ns-V=172
2	-0.03228	0.010554
4	-0.00463	-0.00898
6	-0.01697	-0.01349
8	-0.01325	-0.02807
10	-0.01237	-0.02665
12	-0.01517	-0.03172
14	-0.01958	-0.03567
16	-0.02617	-0.04095

From potential flow theory, it is known that at zero angle of attack, no yaw force should be measured. However, due to small model vibrations, a yaw force was measured at zero angle of attack. This tended to spread the data results. In order to better analyze the data, this measured yaw force at zero angle of attack, was considered a constant value and subtracted out of each angle of attack for each test run. In essence, driving each test run through zero. In some cases, this force at zero angle of attack was exceptionally large and if subtracted out, unduly shifted the entire test run. In these cases, the test run was not zeroed. These cases are noted with an * in the figures containing them. In the Appendix, the measured forces as well as the coefficients are provided.

Magnus Moment. In order to subtract out the beta induced yaw force, the following equation was used:

$$n_{pc} = n_{measured}(1 - \frac{N_s}{Y_p}) - A(\bar{x}) - Y_{pc}(\bar{y}) \tag{5-7}$$

where:

x = the distance from the balance center to the cg. of the model in the X direction = 0.5875 ft

y = the distance from the balance center to the cg. of the model in the Y direction = 0.003843 ft

A = measured axial force (lb_f)

To obtain the Magnus moment coefficients, Eq (3-12) was modified to:

$$C_{n_{pc}} = \frac{n_{pc}}{q\, S_{l_{eff}} \, (\frac{2\pi p_{eff} r}{V})\, \alpha\, l_{eff}} \tag{5-8}$$

In keeping with the procedure used to calculate Magnus forces, any measured moment at zero angle of attack, was subtracted out of the test run expect in the cases where it was exceptionally large as described for the Magnus forces earlier.

Normal and Axial Coefficients

Normal and Axial force coefficients should not change due to the spinning and therefore, the standard nondimensionalization of q S_r, was appropriate and used. However, since the model was at a constant yaw angle when the model was spinning, a small Magnus force was generated in the normal direction. Since the yaw angle was very

small (~ 1 degree), this additional force would be very small when compared to the true normal force. For this reason, it was not subtracted out of the measured normal force.

VI. RESULTS AND DISCUSSION

Magnus Force Effects

Mid Only, Front/Rear Only, and All Sections Spinning. In Figures 6-1, 6-2, and 6-3, there appears to have been some interaction between the mid and rear sections. In Figure 6-3 (all sections spinning), the magnitude of the coefficient did not appear to be the two individual cases (Figures 6-1 and 6-2) added together which was what the potential theory predicted. Instead, all three cases had about equal magnitudes. This shows that there was interaction between the mid and front/rear sections. Interaction means that the vortices coming off a section interfere with the flow over the next section which, in effect, decreases the magnitude of that rear section. Since the predicted values were calculated based on no interaction, this would account for the predicted values being larger than the measured values.

All, Mid Same +10 rps, Mid Opp. +10 rps Sections Spinning. When Figures 6-3, 6-4, and 6-5, were analyzed, there were definite differences in the Magnus force coefficients. When the mid section was spinning at +10 rps in the same direction (Figure 6-4), the Magnus force appeared to be the same magnitude as in the all sections spinning at the same speed case (Figure 6-3). This could mean that the interaction between the mid and rear sections effectively canceled out the increased magnitude of the mid section due to the increased spin rate. Or, the increased Magnus force due to the differential was too small to be measured accurately. However, in Figure 6-6, when the mid section was

spinning in the opposite direction at a +10 rps, there was a noticeable change in the Magnus force coefficient. In theory, the magnitude generated should be small but not positive, however, in this case, the magnitude of the force was positive. When the mid section was spinning opposite to the front/rear sections, the mid section generated enough force to totally cancel out the front/rear generated force and still have some magnitude left. What can't be determined here was the effect of the differential. To determine this, testing of the mid section spinning in the opposite direction at the same spin rate as the front/rear sections needs to be done. An important result of this case was that this type of spinning could effectively cancel Magnus force generation which would eliminate the problem of trajectory drift that a Magnus force introduces.

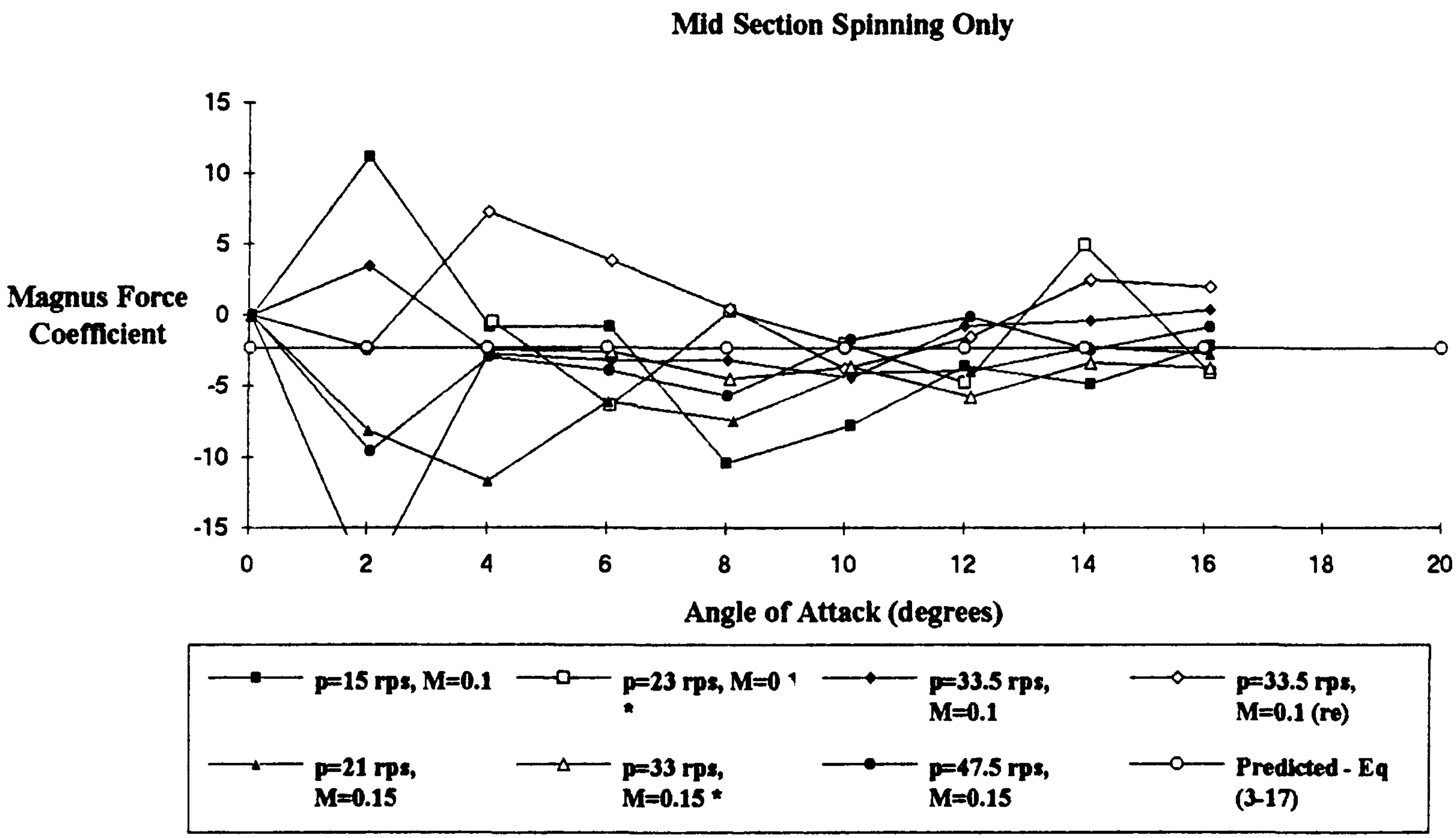

Figure 6-1. Magnus Force Coefficient - Mid Section Only

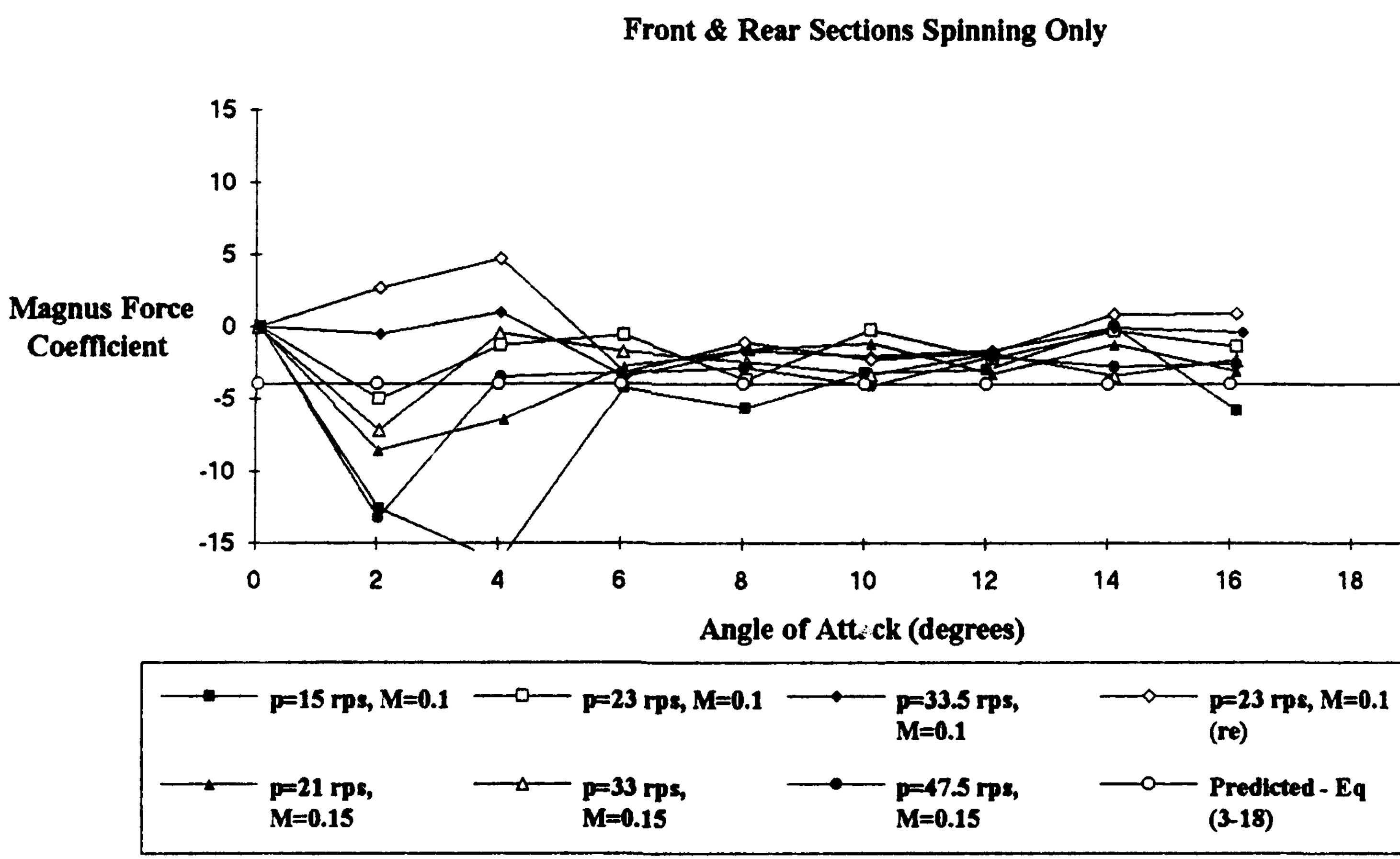

Figure 6-2. Magnus Force Coefficient - Front/Rear Sections Only

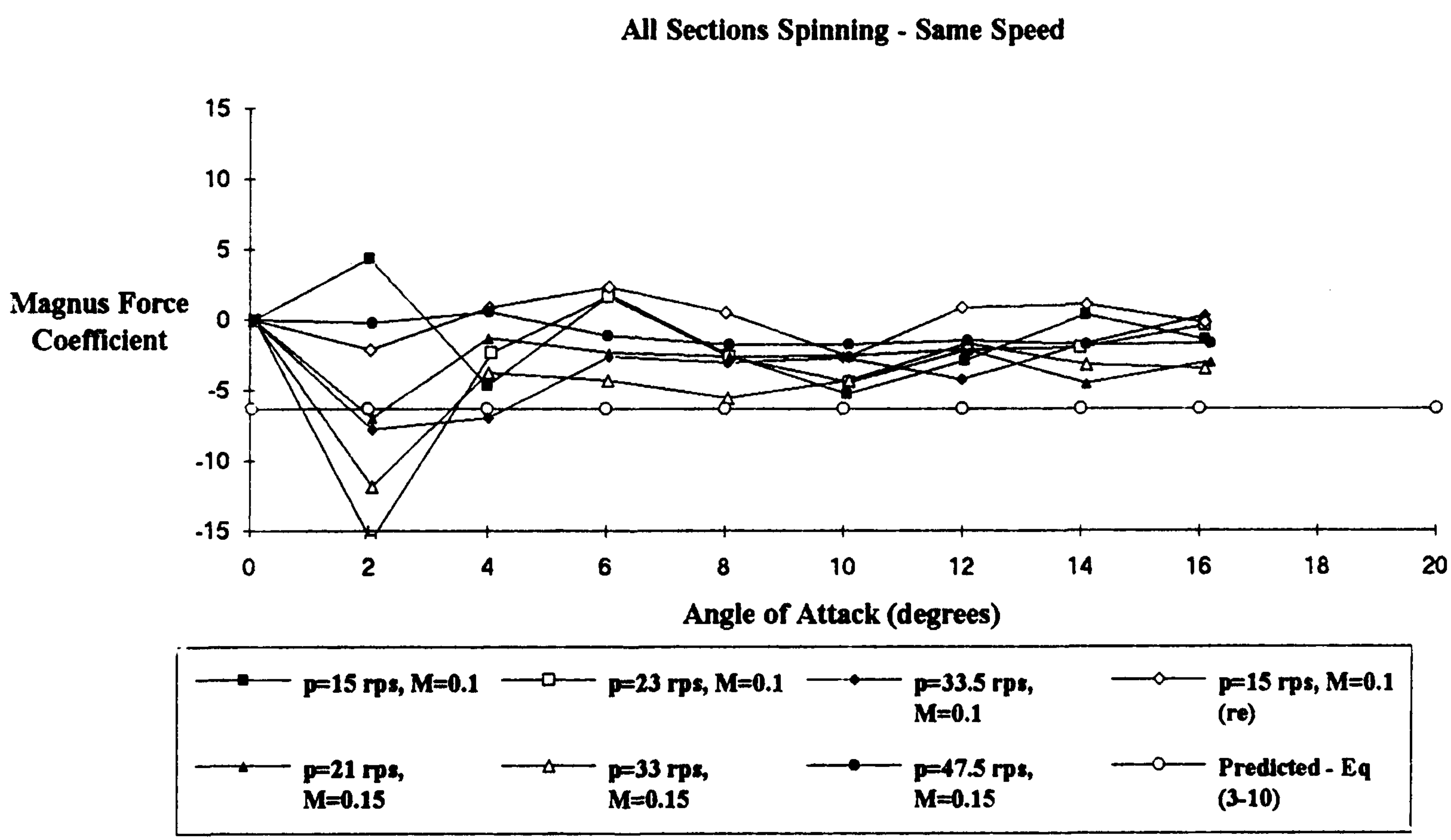

Figure 6-3. Magnus Force Coefficient - All Sections Same Speed

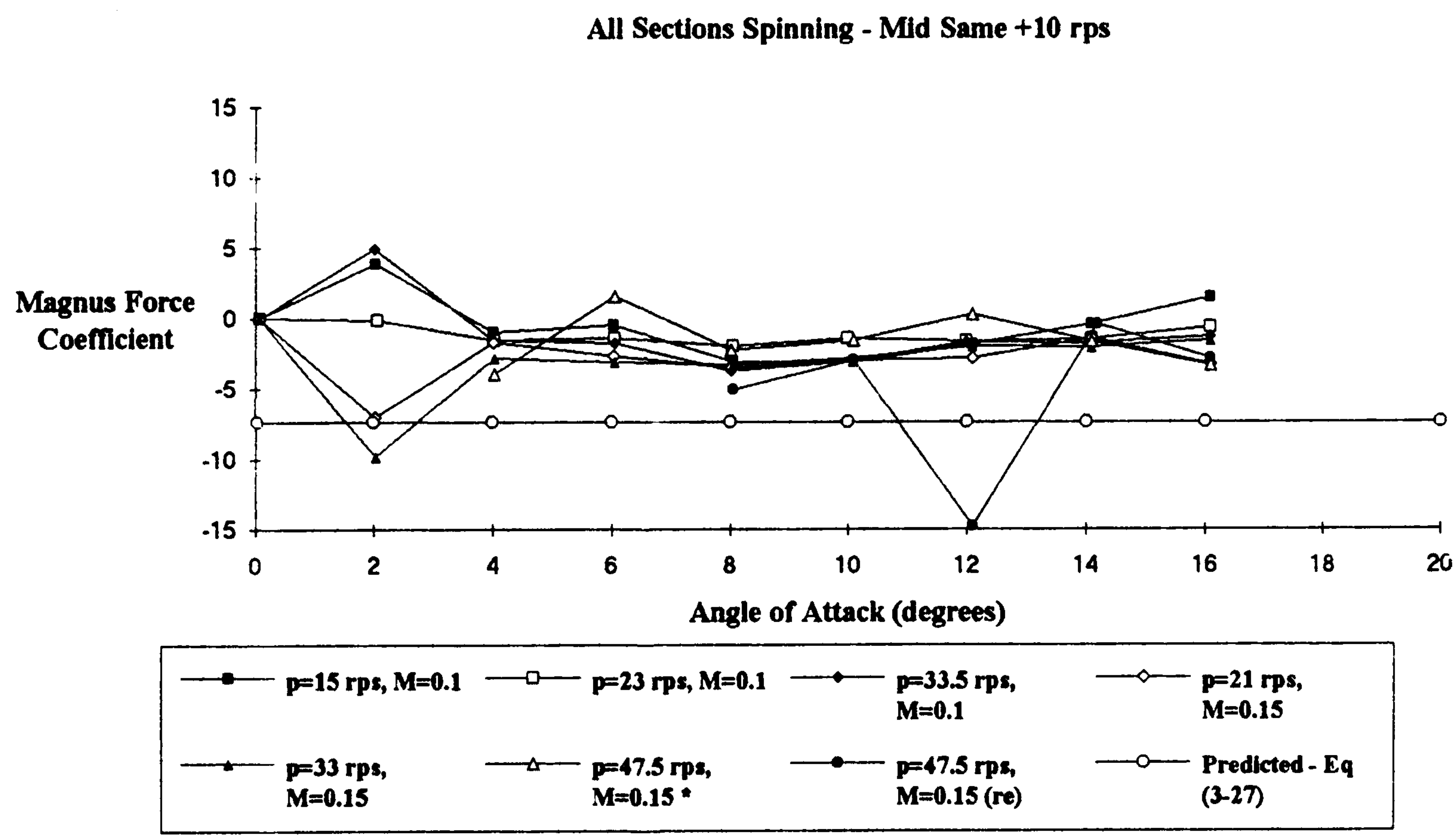

Figure 6-4. Magnus Force Coefficient - Mid Section +10 rps Same Direction

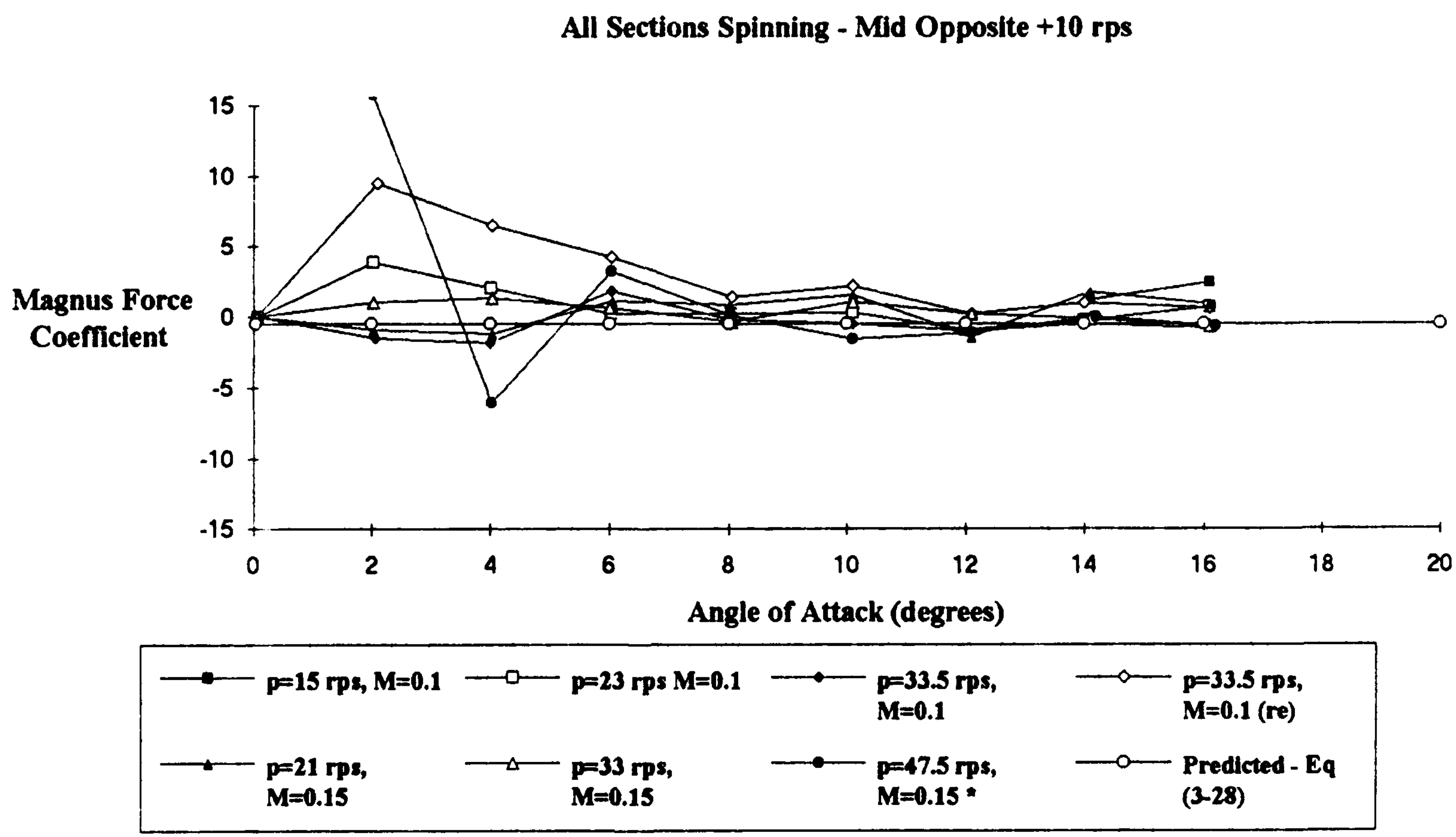

Figure 6-5. Magnus Force Coefficient - Mid Section +10 rps Opposite Direction

Magnus Moment

Mid Only and Front/Rear Only Spinning. In Chapter II, to predict the Magnus moment it was assumed that the center of pressure for each section was at it's midpoint. In Figures 6-6 and 6-7, this assumption is shown to be wrong. Though the moments were small in Figures 6-6, and 6-7, they had about the same positive magnitude. In order for the moments to be positive when their respective Magnus forces were negative, the model's center of pressure must be slightly behind the cg which was located in the rear section but not at it's midpoint. Also, the moment was essentially constant which means that the center of pressure did not move with increased angle of attack since the Magnus forces were also essentially constant.

All, Mid Same +10 rps, Mid Opp +10 rps. From Chapter II, for all sections spinning at the same speed, the moment was taken about the cg and was zero. In Figure 6-8, for this case, the trend for the moment was a slightly positive magnitude. This means that the center of pressure was behind the cg as was the case in Figures 6-6 and 6-7. However, in Figure 6-9, when the mid section was spinning at +10 rps faster in the same direction, the moment was approximately zero. This means that the center of pressure moved forward to the cg. since the forces for both cases were essentially equal (Figures 6-3 and 6-4). Finally, in Figure 6-10, when the mid section was spinning opposite, the moment was slightly negative. Since the Magnus force for this case was a positive magnitude, the center of pressure must also be behind the cg. slightly as in the previous cases. Overall, the moments were very small. The differential spinning in either direction did not seem to greatly affect the moment generated.

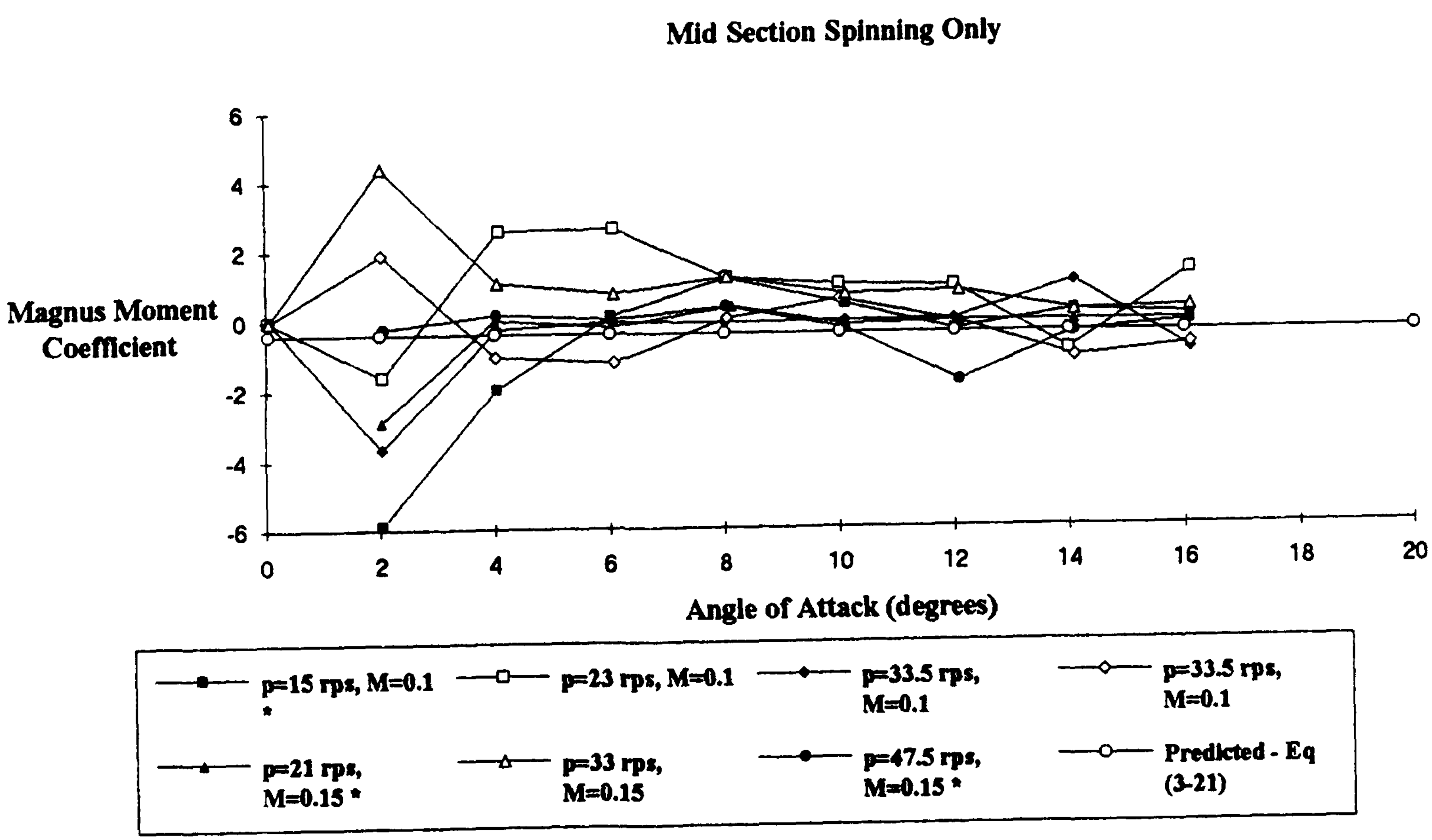

Figure 6-6. Magnus Moment Coefficient - Mid Section Only

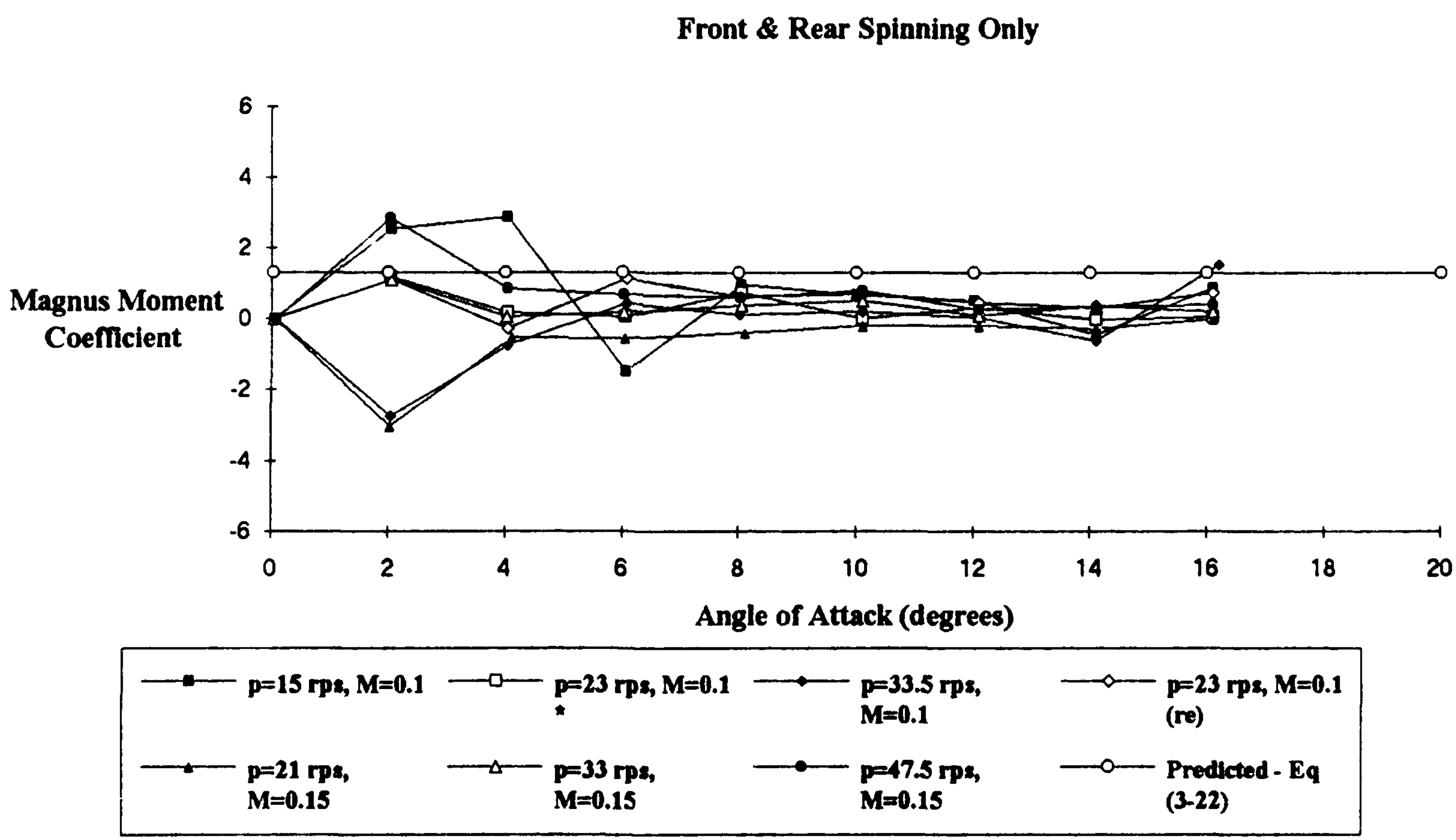

Figure 6-7. Magnus Moment Coefficient - Front/Rear Sections Only

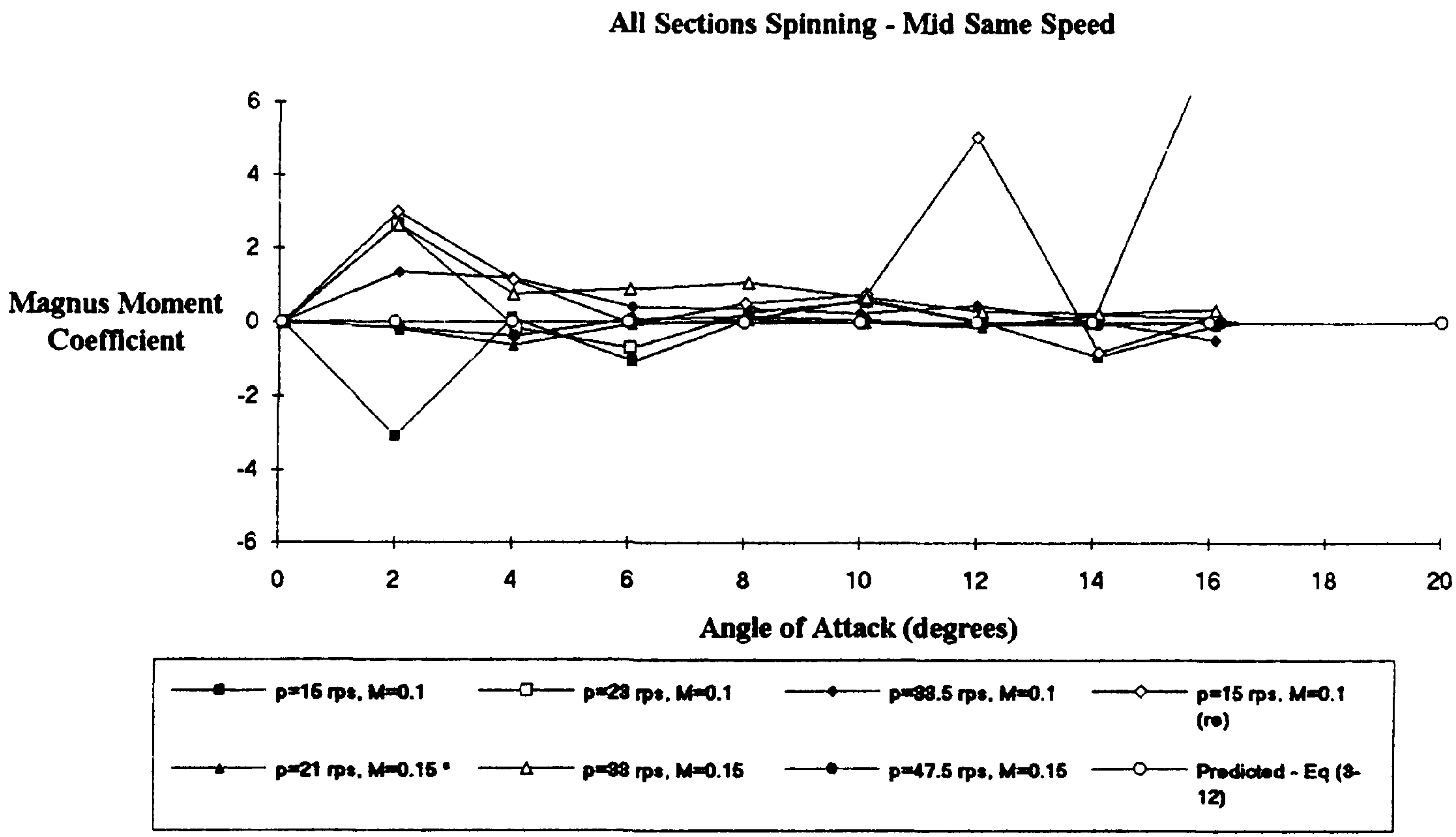

Figure 6-8. Magnus Moment Coefficient - All Sections Same Speed

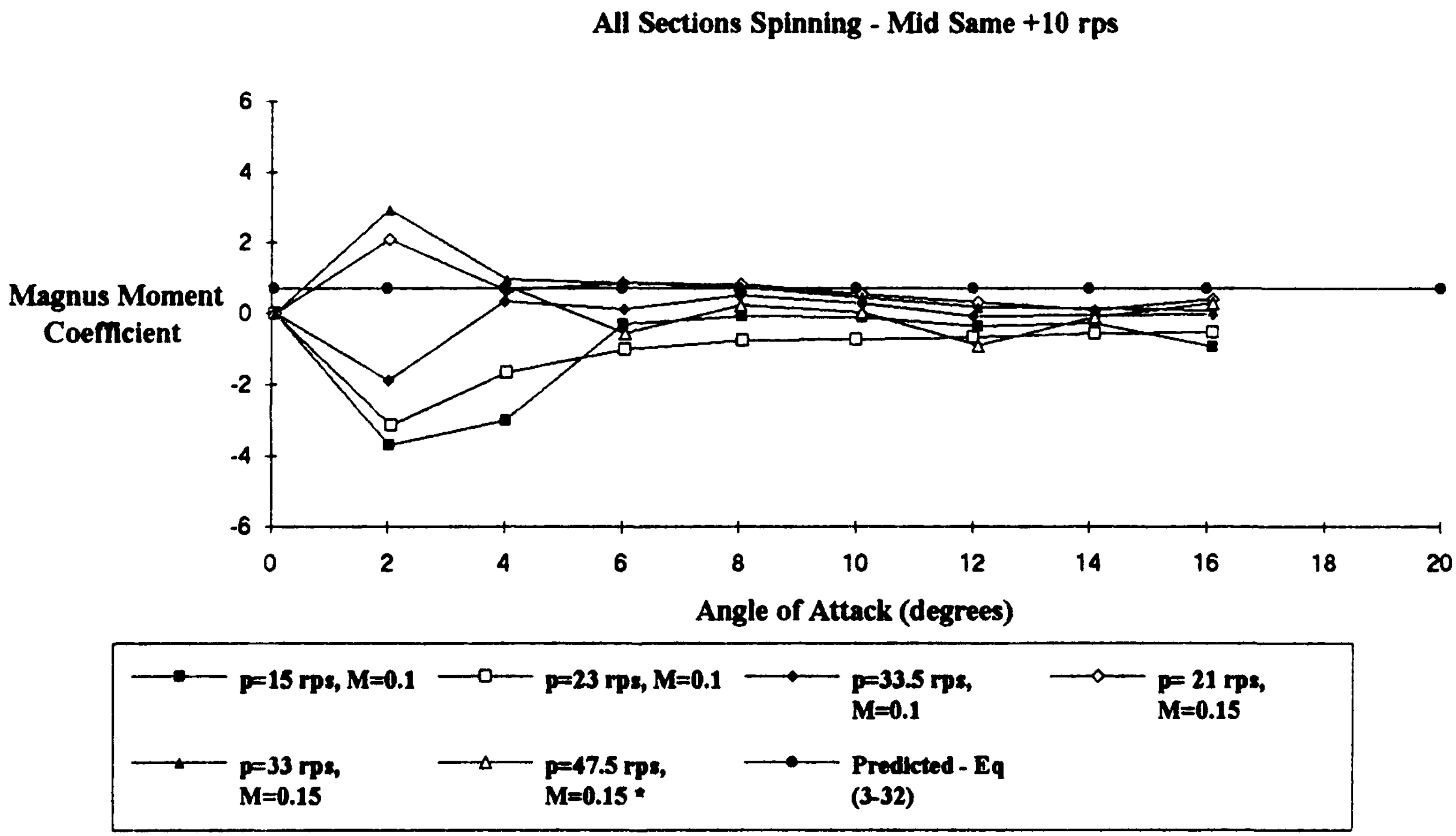

Figure 6-9. Magnus Moment Coefficient - Mid Section +10 rps Same Direction

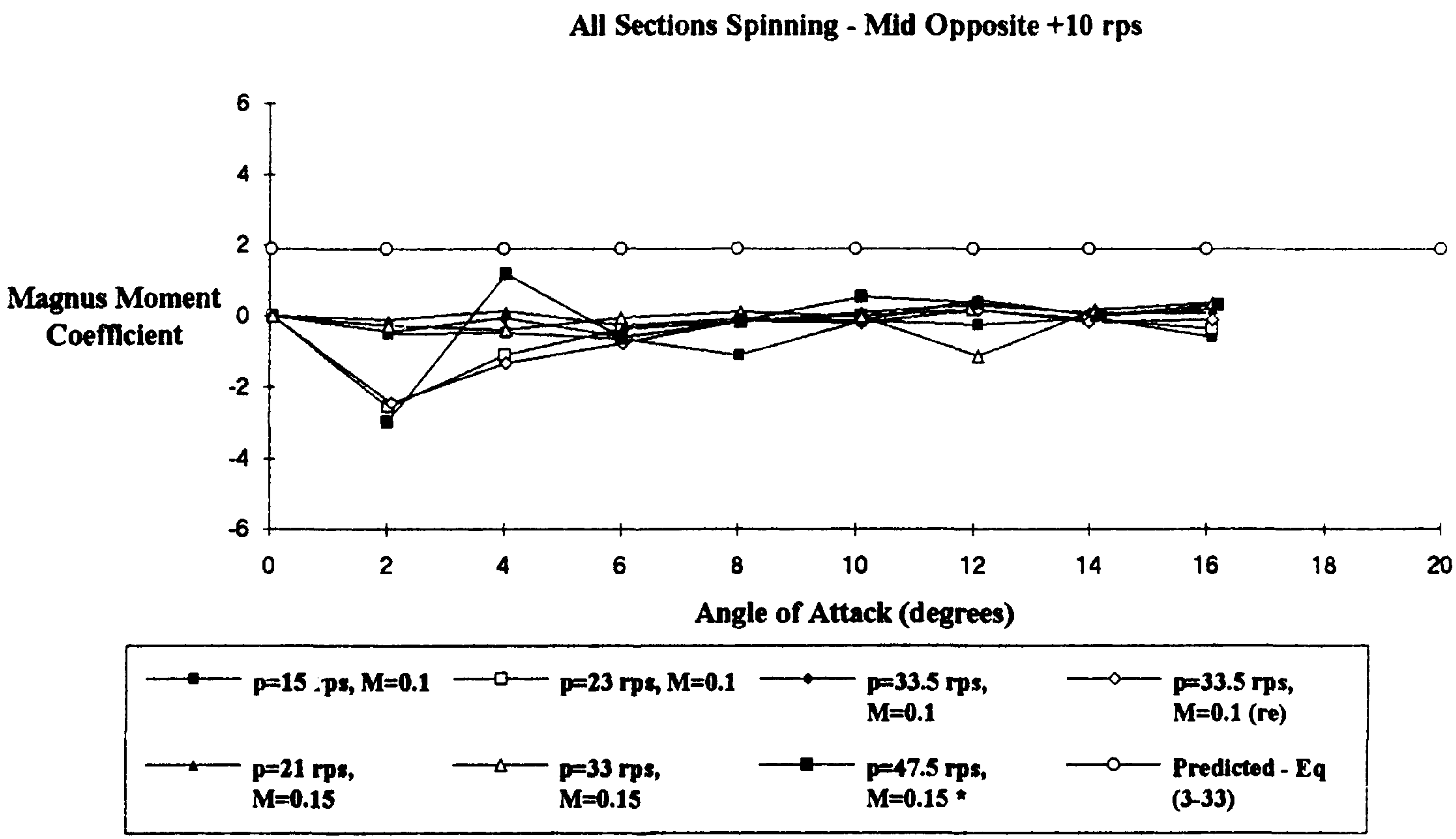

Figure 6-10. Magnus Moment Coefficient - Mid Section +10 Opposite Direction

Normal Force

In theory, the normal force on a spinning missile should not be affected if it is not at a yaw angle because there would be no cross flow velocity to generate an additional normal force. In this experiment, there was a constant yaw angle of ~1 degree, but it was determined to be negligible. To determine if the normal force had increased in magnitude, the normal coefficient of the no spin case was compared to coefficients obtained from a missile computer modeling program called Missile DATCOM. This program adapts the USAF Stability and Control DATCOM Methodology to missile shapes. It is typically used to predict aerodynamic performance for preliminary designs based on data gathered from previous missile programs. For this experiment, the physical characteristics of the model were loaded into the program and the aerodynamic coefficients predicted. It must be noted, however, that this model had a length to diameter ratio of about 26.5 which is out of the range of typical missiles. Therefore, the DATCOM predictions were only estimates based on extrapolations. In Figures 6-11 through 6-15, the DATCOM predicted value was consistently higher than the measured normal force. Though there was some variation in the coefficients which could have been due to the beta induced Magnus force, the curves were all essentially the same. In Figure 6-16, the normal coefficients for the no spin cases were also compared to the predictions. These verify that DATCOM's prediction was too large for this model. However, the no spin cases were the same as the spinning cases and could be compared with the spinning cases. For example, when looking at 10 degrees

angle of attack, the normal coefficients throughout the six cases (Figures 6-11 through 6-16) were essentially a magnitude of one. This verified the fact that the normal coefficient was not affected by spinning.

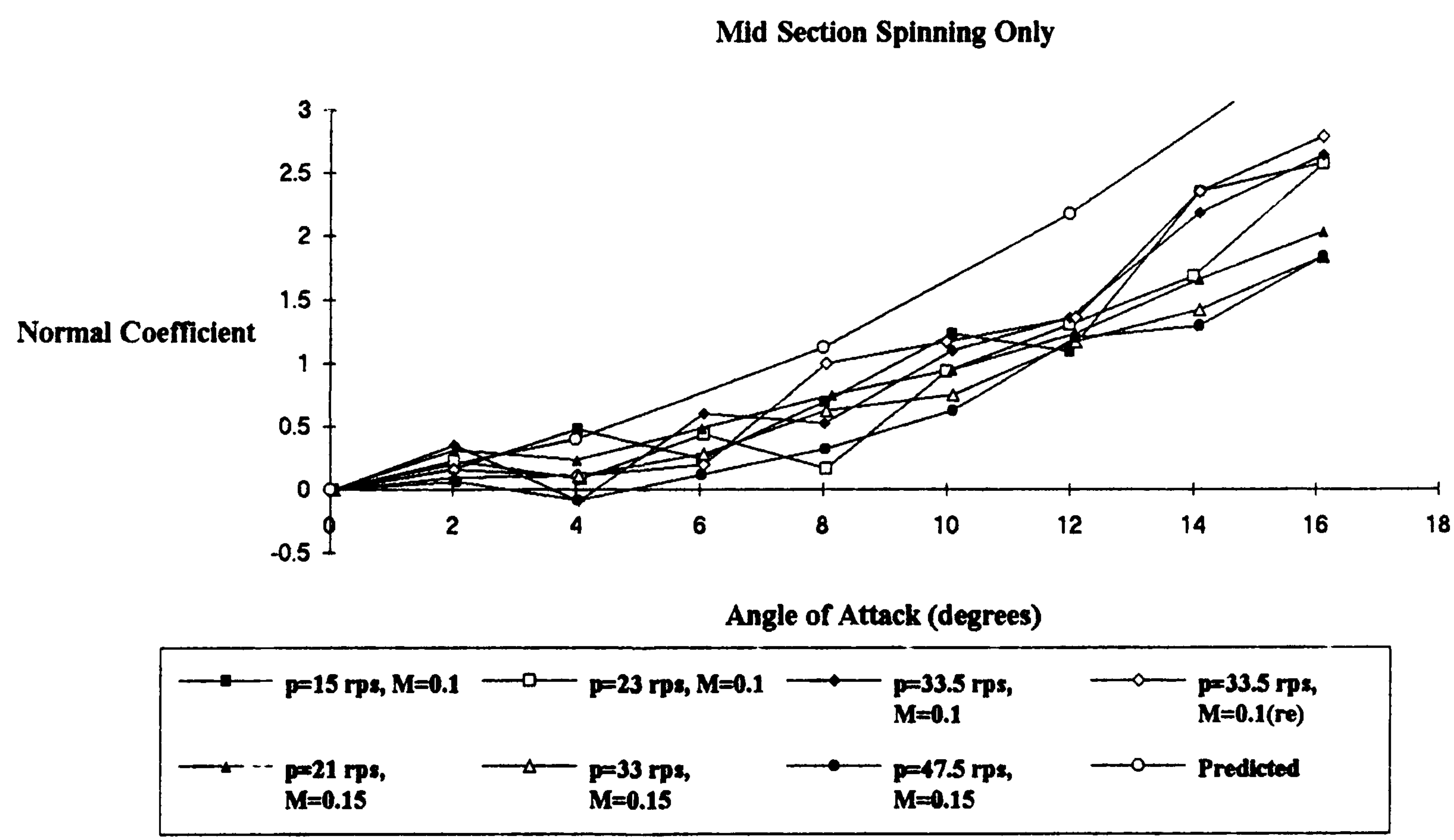

Figure 6-11. Normal Force Coefficient - Mid Section Only

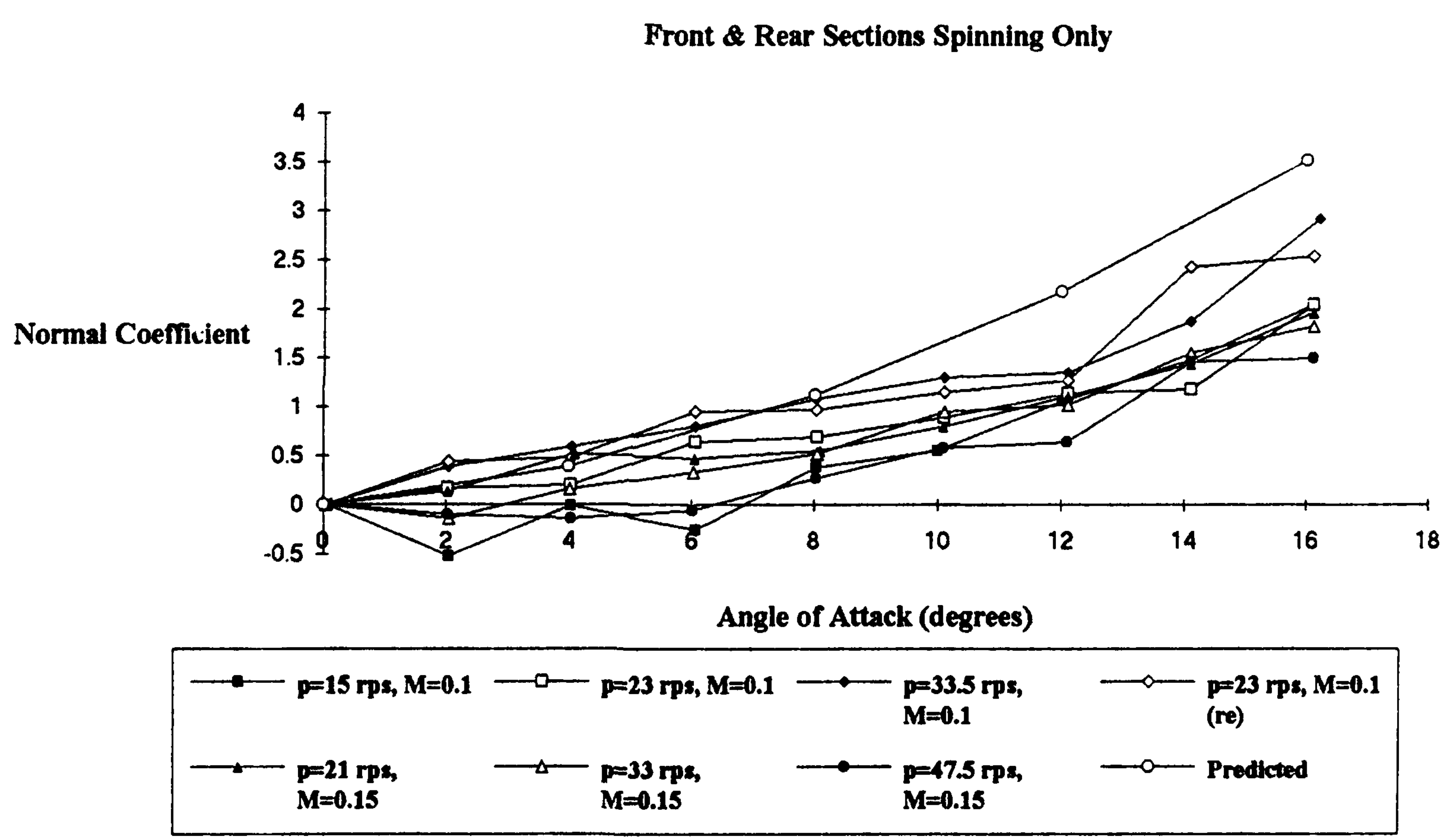

Figure 6-12. Normal Force Coefficient - Front/Rear Sections Only

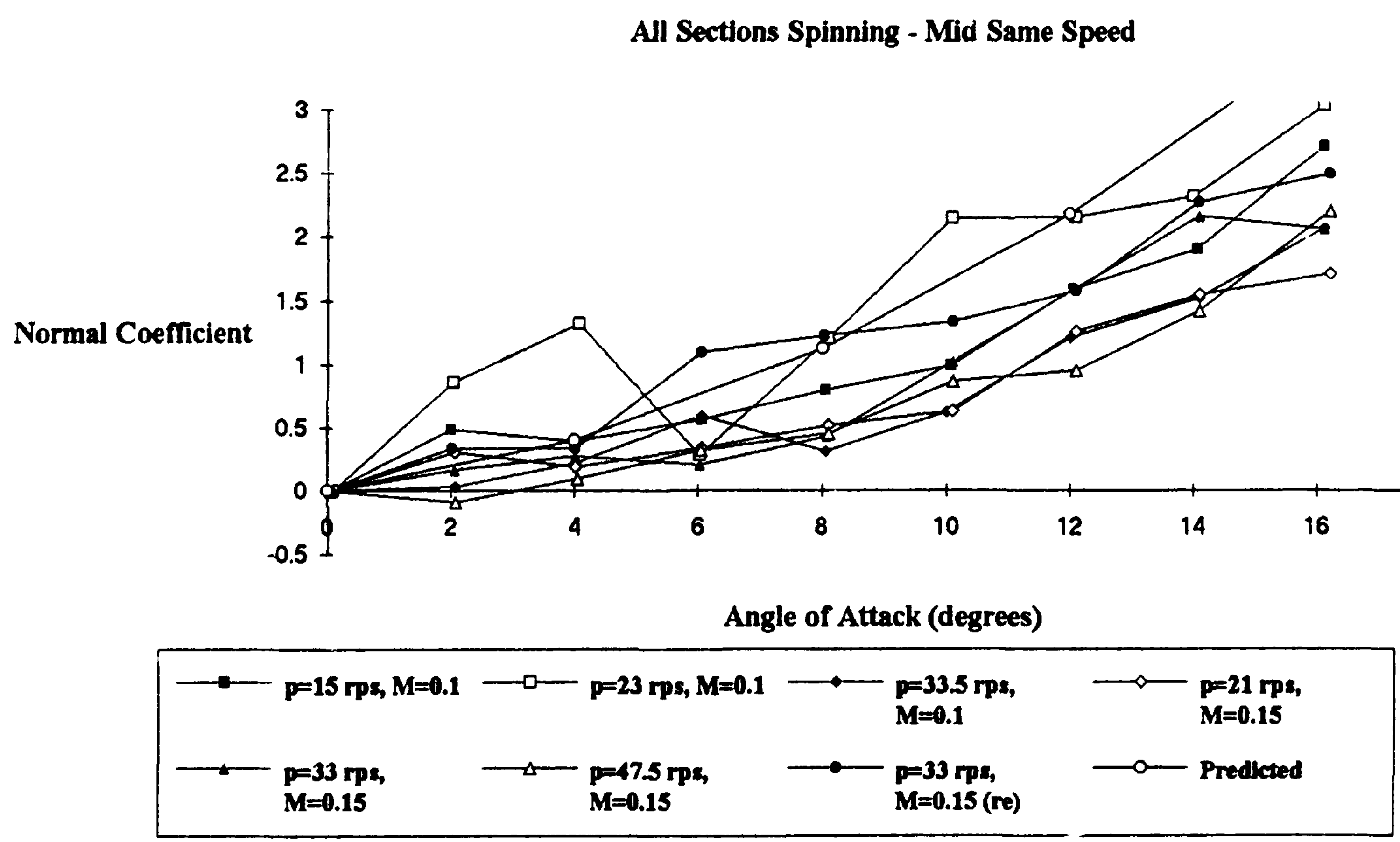

Figure 6-13. Normal Force Coefficient - All Sections Same Speed

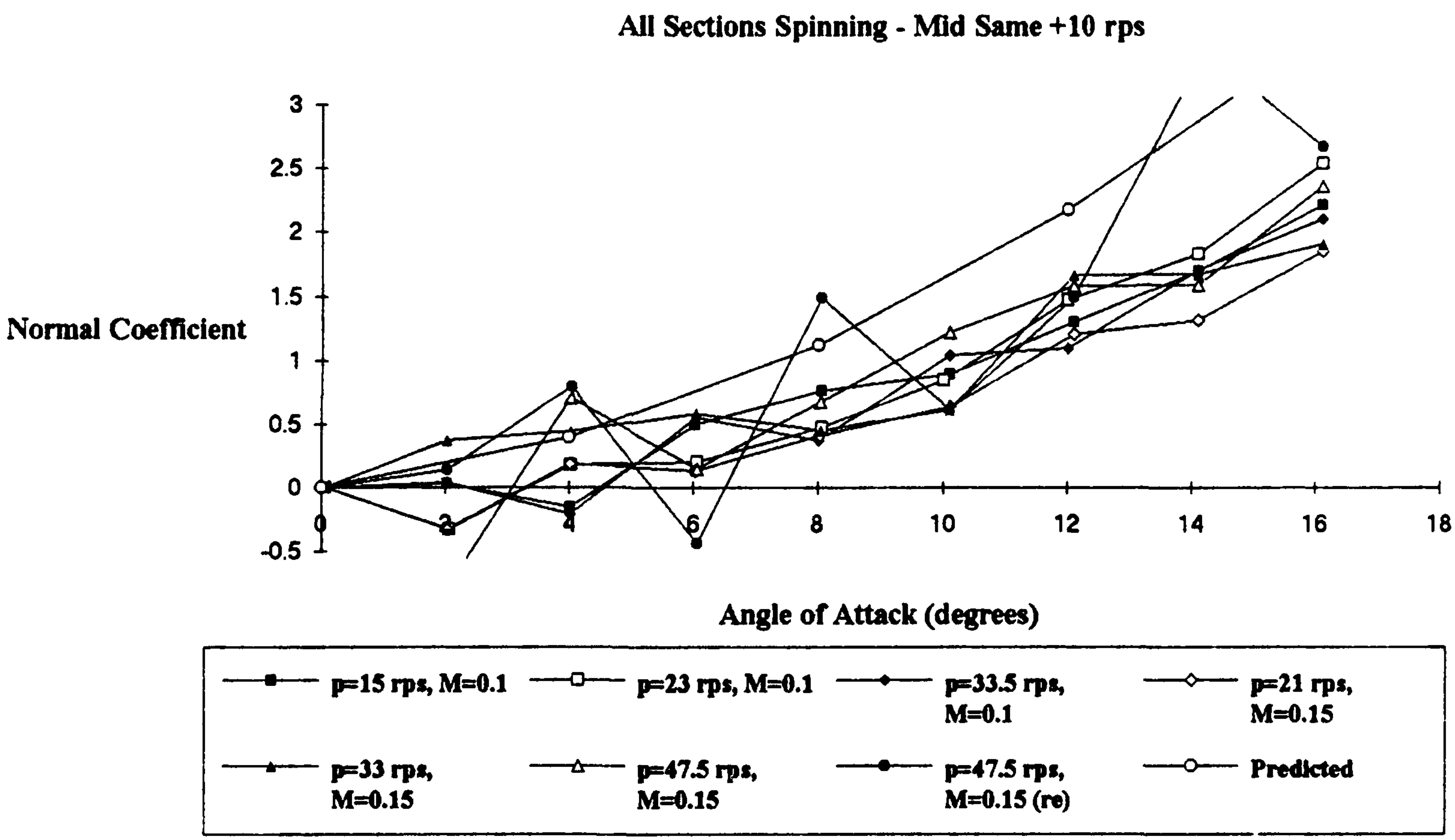

Figure 6-14. Normal Force Coefficient - Mid Section +10 rps Same Direction

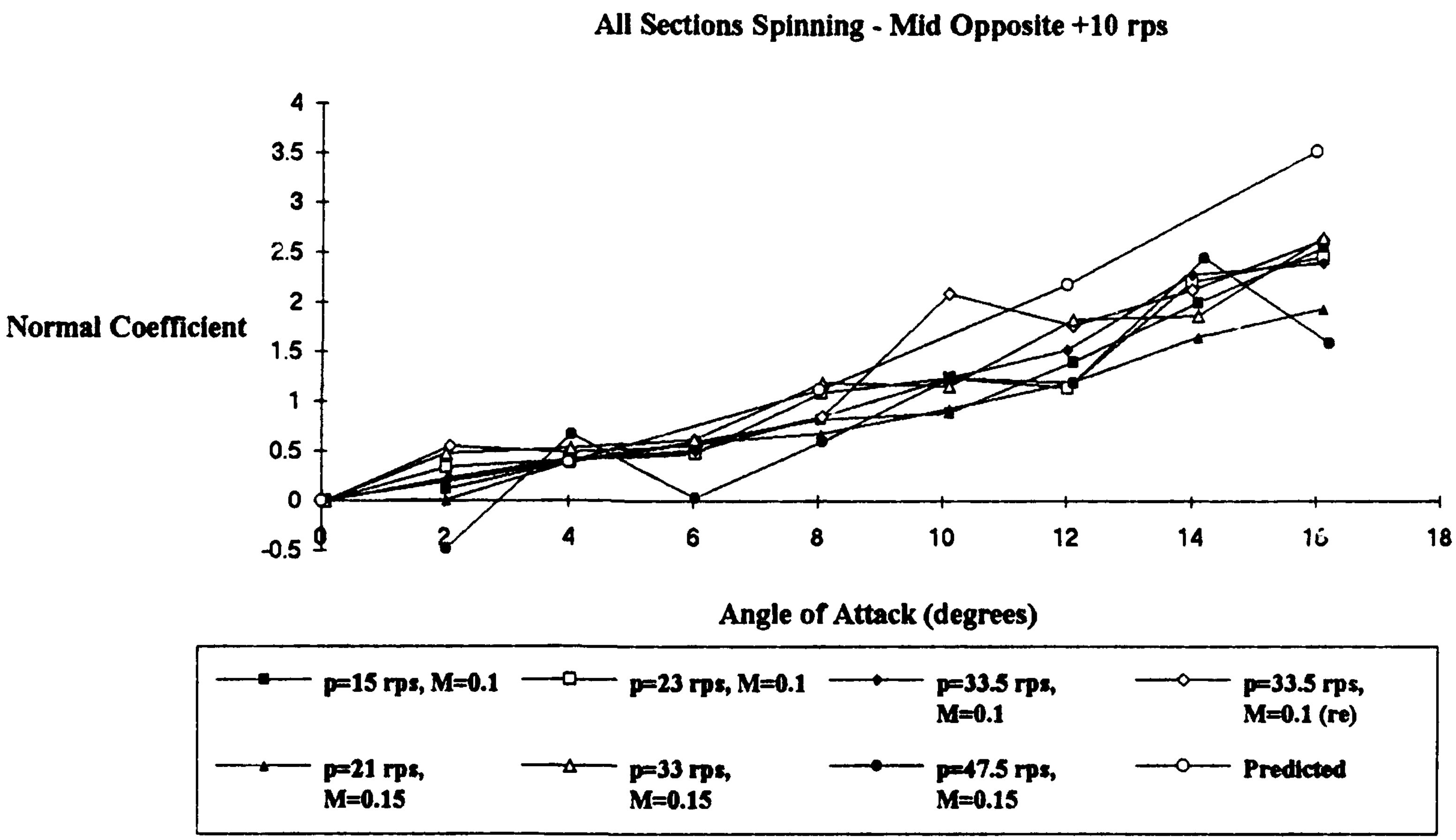

Figure 6-15. Normal Force Coefficient - Mid Section +10 rps Opposite Direction

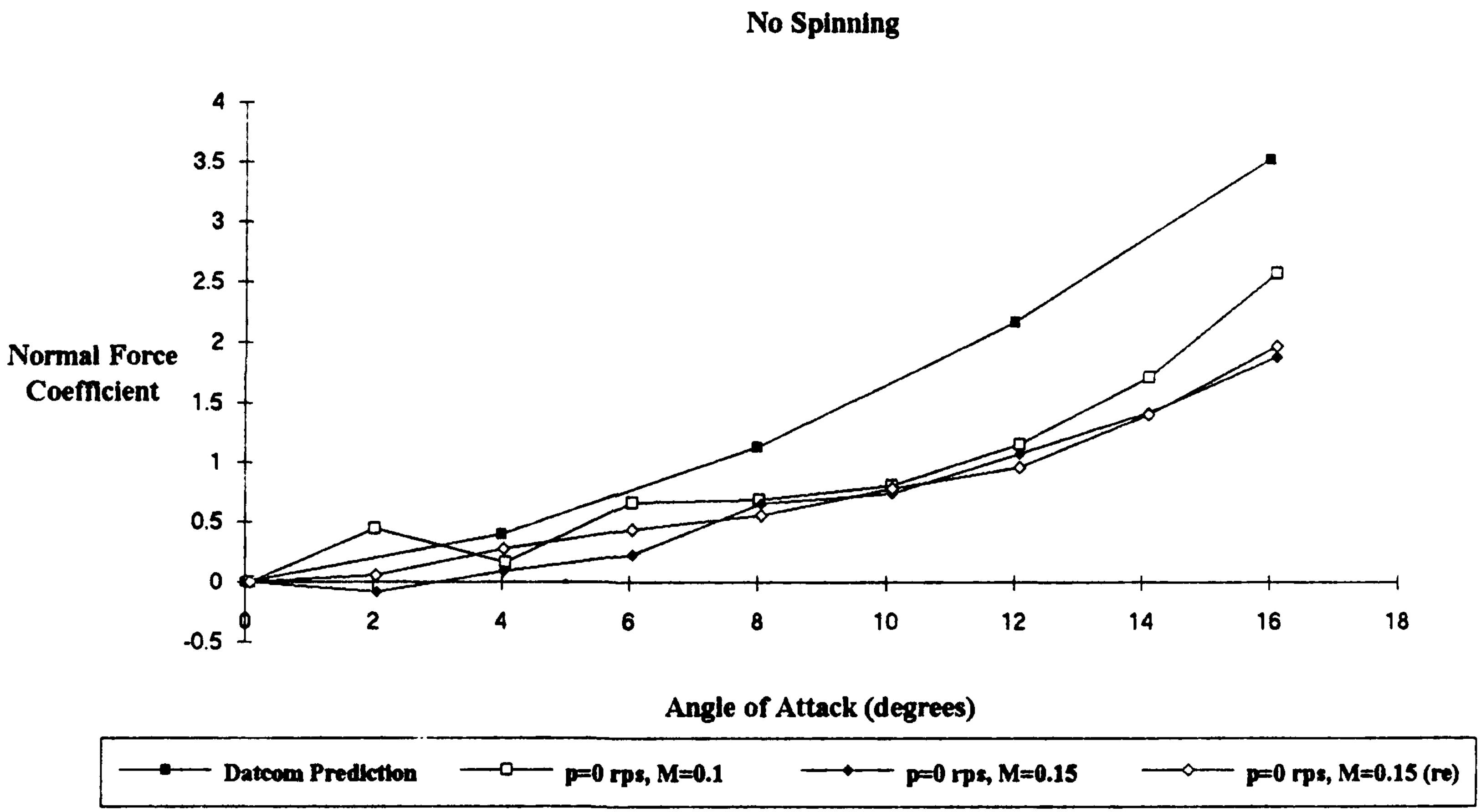

Figure 6-16. No Spin Normal Coefficient

Axial Force

As in the previous section, the Missile DATCOM program was used to generate axial force coefficients to compare to the test results. Figure 6-17 shows the DATCOM results versus the results for the no spin cases. The measured axial force coefficients had much greater variation than did the normal force coefficients. However, in Chapter IV, Tare discussions, the axial force error could be as large as 0.04 lb_f. As with the normal coefficient, the predicted values were larger than the actual. In Figures 6-18 through 6-22, the axial force coefficients are shown. In all cases except for the mid section spinning opposite at +10 rps, the trend was the same: at zero angle of attack, the coefficient had a magnitude of ~0.3 +/- 0.1 and then gradually decreased toward zero magnitude at ~ 10 degrees. This is consistent with the general trend of an axial coefficient for a missile as shown in Figure 6-23, taken from Chin's book on missile design (2:18). In Figure 6-22, when the mid section was spinning opposite, the trend was opposite. Instead of decreasing with larger angles of attack, the magnitude increased. This effect was probably due to the vortices of the mid and rear sections coming off in opposite directions and interfering with each other.

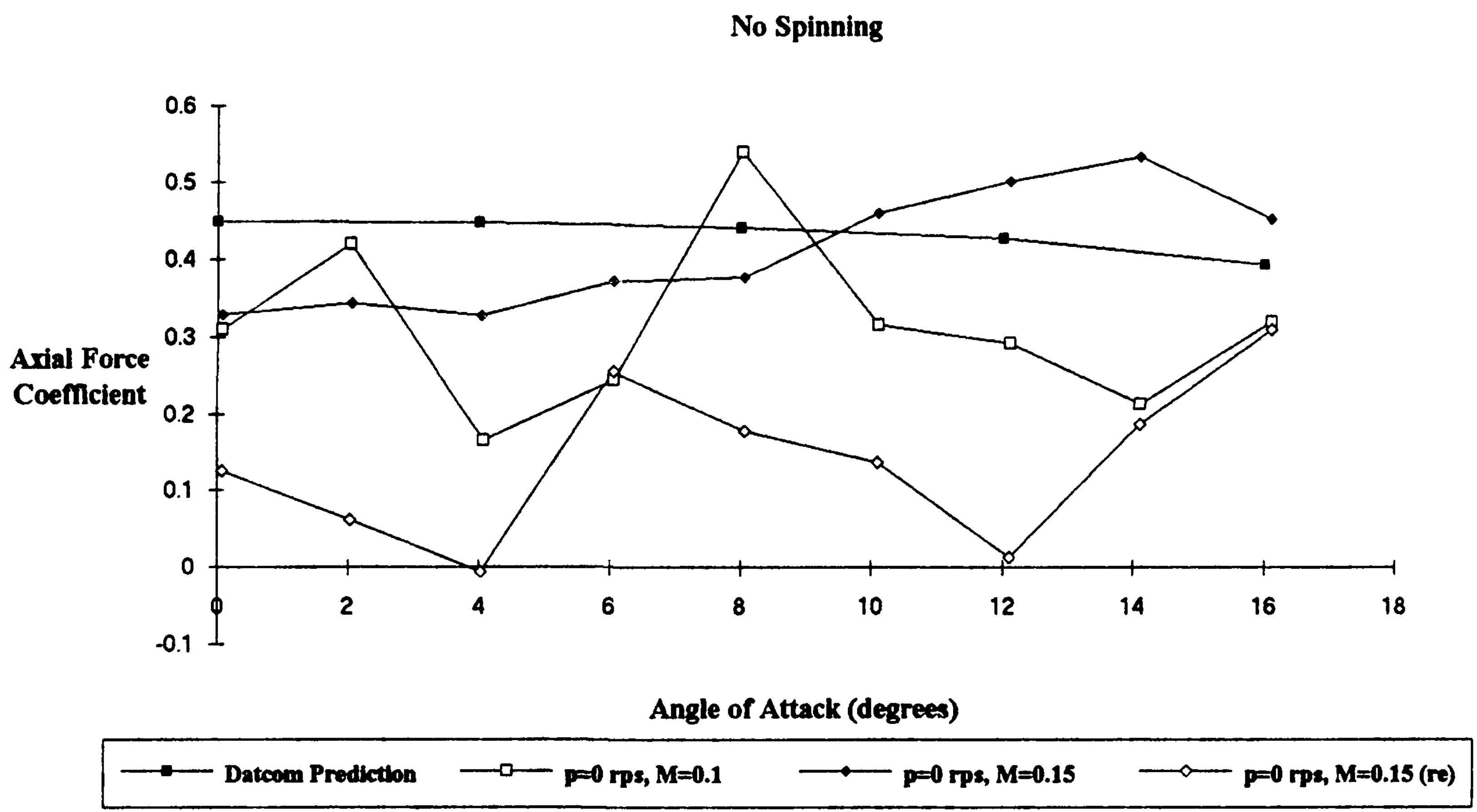

Figure 6-17. Axial Force Coefficient - No Spin

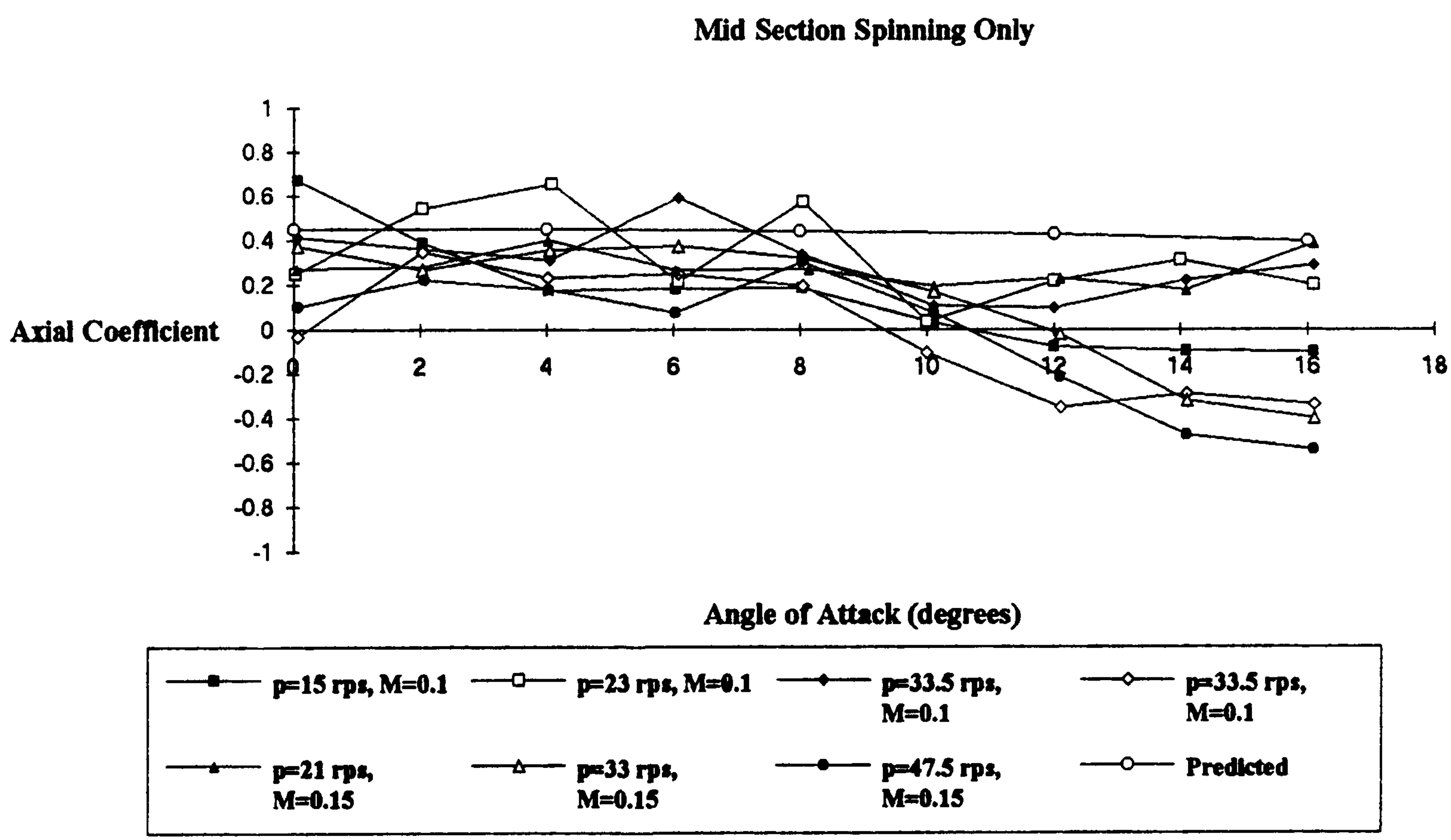

Figure 6-18. Axial Force Coefficient - Mid Section Only

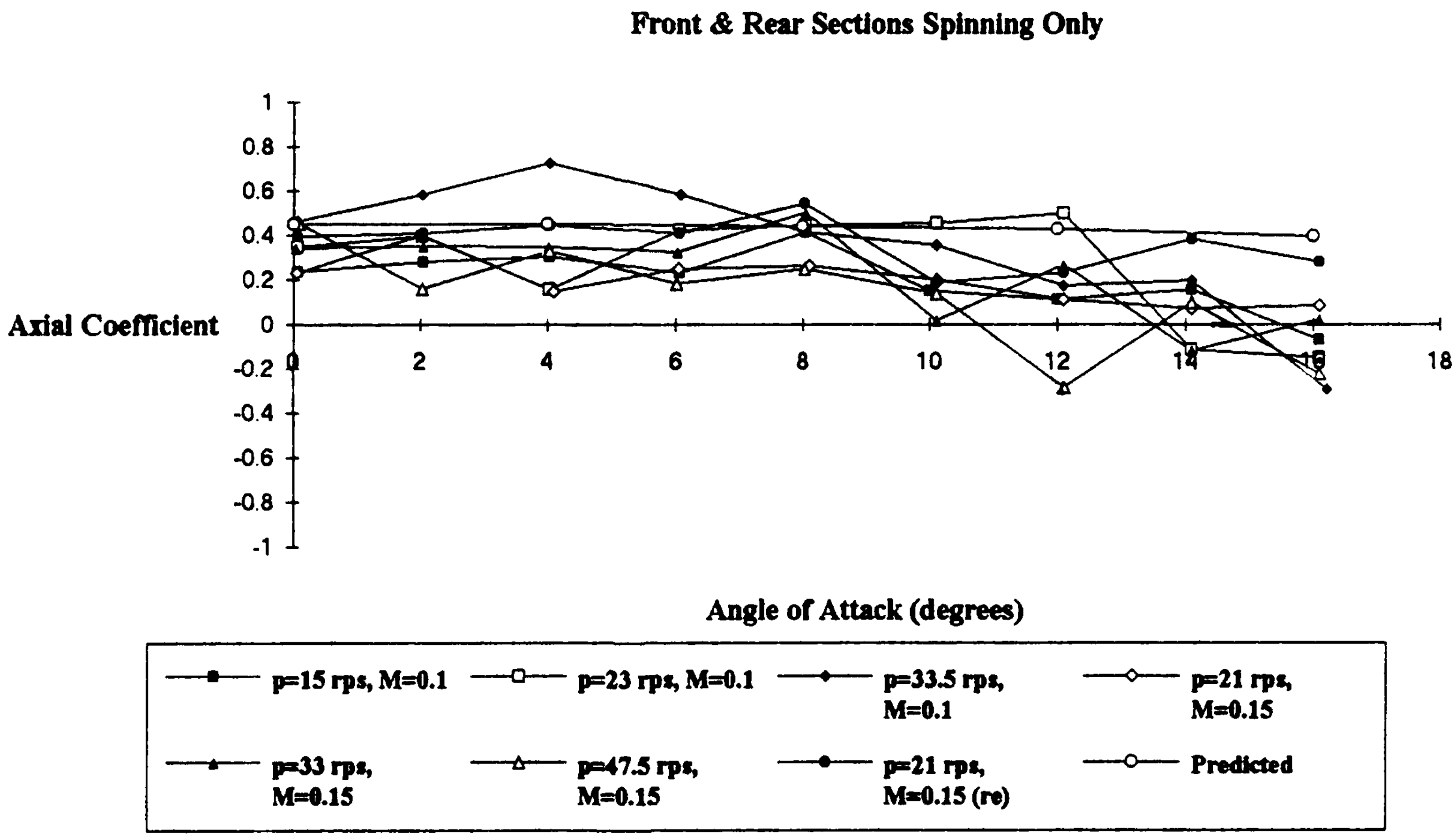

Figure 6-19. Axial Force Coefficient - Front/Rear Section Only

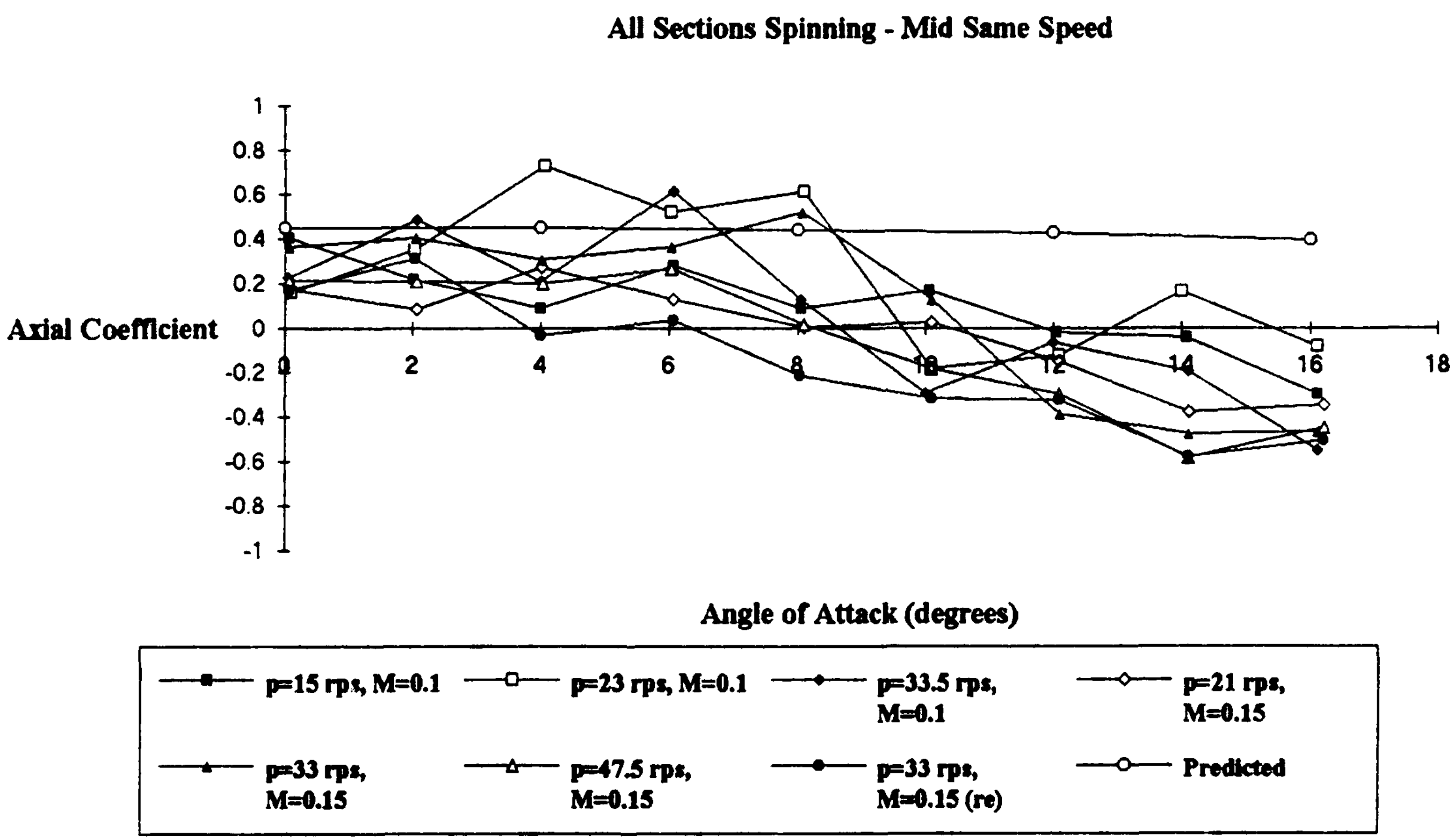

Figure 6-20. Axial Force Coefficient - All Sections Same Speed

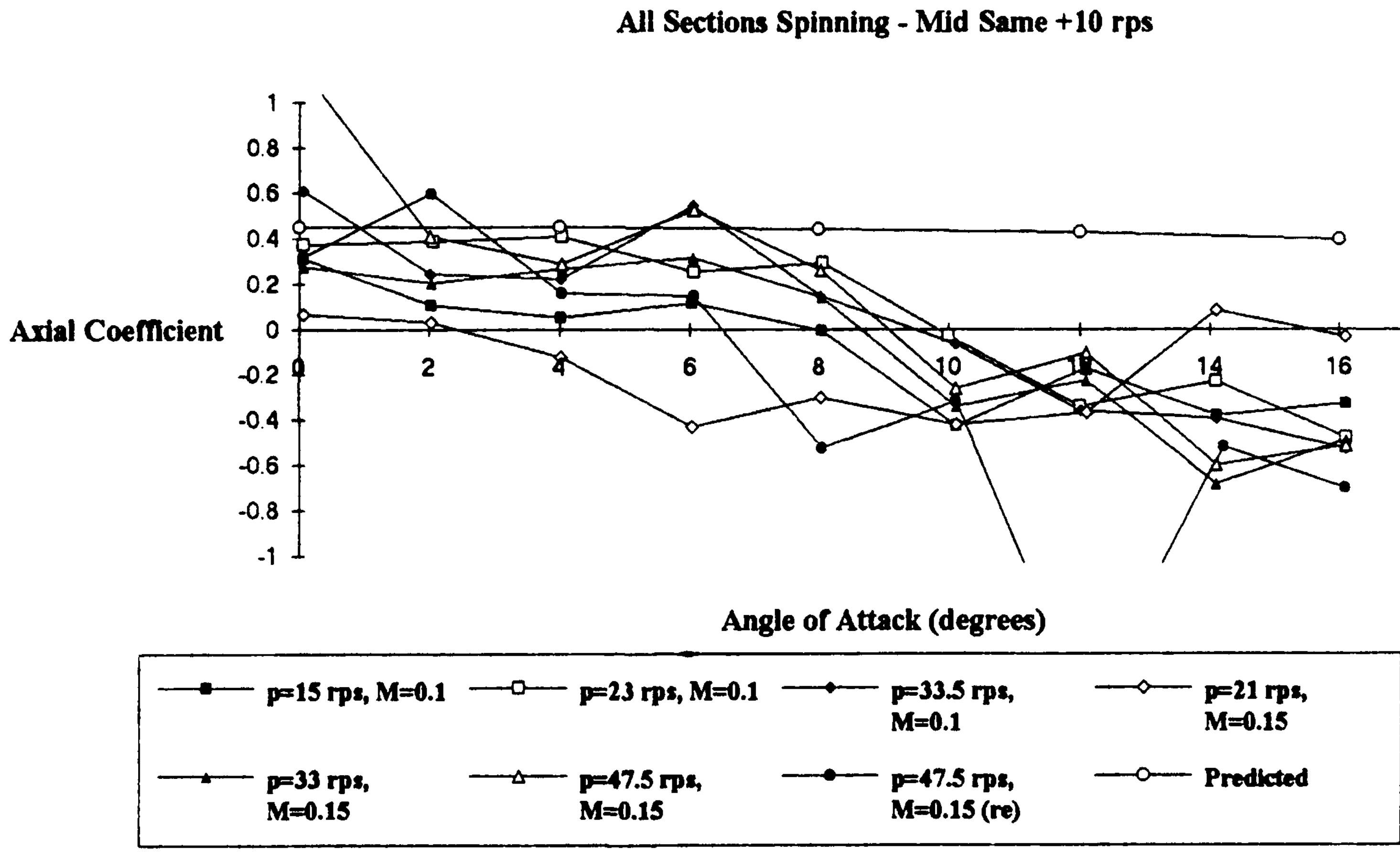

Figure 6-21. Axial Force Coefficient - Mid Section +10 rps Same Direction

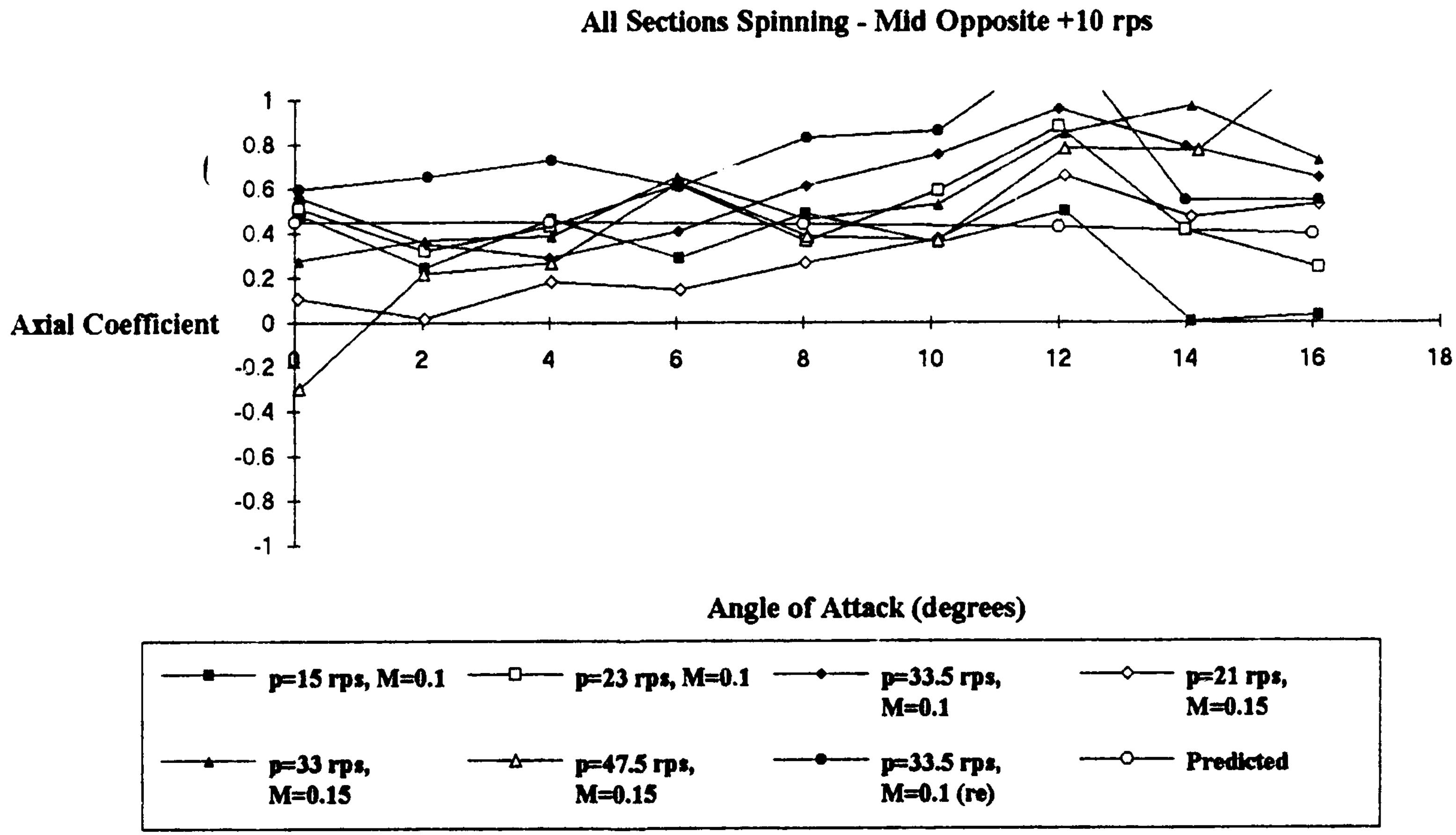

Figure 6-22. Axial Force Coefficient - Mid Section +10 rps Opposite Direction

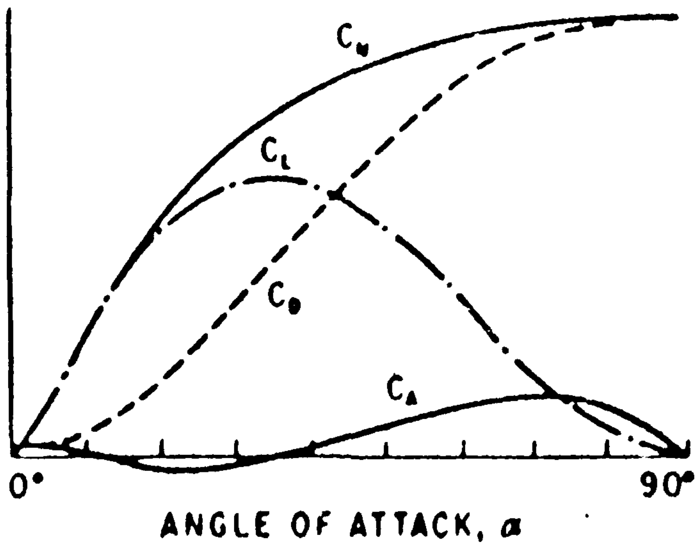

Figure 6-23. Typical Axial Coefficients (2:18)

VII. CONCLUSIONS

Although definitive results were not obtained, general trends were found. In most cases, the potential theory and Missile DATCOM predictions were too large. This was due to the assumptions made in potential flow theory and extrapolations made for the DATCOM results. It was found that there was flow interaction between the mid and rear sections which decreased the magnitude of the Magnus force. This also tended to cancel out the effect of the spin rate differential in the same direction since in Figures 6-3 and 6-4, the magnitudes were the same. However, with a spin differential in the opposite direction, the mid section seemed to dominate and canceled out the Magnus force generated by the rear section (Figure 6-5). Though the Magnus forces varied, the moments they generated were quite small and the center of pressures for the five cases did not vary much. The center of pressure stayed slightly behind the cg. and did not vary with angle of attack. When the normal and axial force coefficients were examined, they essentially confirmed that spinning, whether differentially or not, did not change their magnitudes. Overall, these results show that for the Folding Finned Aircraft Rocket program, the Magnus effects should have a very small, if any, effect on the FFAR's trajectory. But, if possible, the payload section should be spun opposite to the front/rear sections so that no Magnus moment is generated.

VIII. RECOMMENDATIONS

1. Though general trends could be seen, the forces measured in this experiment were not very repeatable. This may have been due to the wind tunnel velocities that were used. For further study, tests should be done in a higher speed tunnel. This could eliminate some of the noise in the data as well as better reflect the speeds the FFAR flies at. However, at higher speeds, model vibration might be a greater problem so that preliminary testing at various speed would need to be done first.

2. The front and rear sections were supposed to spin together, but it was not possible to construct this model to have them internally connected to insure this. More accurate results might be measured if the design was changed to enable these two sections to be connected.

3. To better understand the effect of the mid section spinning faster than the rest of the model, increasing the mid section spin by a percentage versus a set rate, i.e. +10 rps, might yield more collapsible data.

4. The possibility of using air to turn the sections should continue to be explored. If higher spin rates are desired, air pressure may be the only way to obtain them in such a small diameter model.

APPENDIX : DATA TABLES

Mid Section Spinning Only													
V=120 ft/s	p=15 rps												
Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns		CN zero	CY zero	CA	Cn zero
0	16.4	121	5.6468	0.0138	-0.00039	0.102525	-0.0156	0.129663		0	0	0.673	432.8237
2.03	16.6	121	5.7211	0.0148	0.024209	0.059366	-0.00926	-0.03228		51.29362	11.18622	0.385	-5.89424
4.03	16.5	121	5.7954	0.0041	0.072343	0.026362	-0.0131	-0.00463		75.86398	-0.85188	0.172	-1.95918
6.03	16.4	121	5.8697	-0.0109	0.036257	0.027726	-0.0125	-0.01697		25.37548	-0.86341	0.182	0.111978
8.02	16.3	120	5.944	-0.126	0.104473	0.028314	-0.0217	-0.01325		53.79426	-10.4676	0.187	1.170177
10.1	16.2	120	5.944	-0.116	0.185093	0.004394	-0.0428	-0.01237		76.02253	-7.76069	0.0292	0.416814
12	16.2	120	6.05545	-0.0672	0.164025	-0.01138	-0.0601	-0.01517		55.6739	-3.59431	-0.0756	-0.34218
14.1	16.1	120	6.0926	-0.11	0.351449	-0.01397	-0.046	-0.01958		101.404	-4.84337	-0.0934	0.202187
16.1	16.1	120	6.0926	-0.066	0.385846	-0.01525	-0.0261	-0.02617		97.48957	-2.1825	-0.102	0.090384
12	16.4	121	6.12975	-0.0962	0.23308	0.015691	-0.0602	-0.01657		77.79161	-5.01948	0.103	-0.11171
8.02	16.6	121	6.12975	0.0345	0.109943	0.058132	-0.0169	-0.01517		54.34567	2.848693	0.377	-1.42948
4.04	16.6	122	6.12975	0.0181	0.033461	0.077099	-0.0137	-0.01324		33.37535	2.788042	0.5	-2.23492
0.0503	16.6	122	6.0926	-0.0325	0.035928	0.066151	-0.00935	0.393536		2893.537	-594.717	0.429	-2033.87

V=120 ft/s p=23 rps

Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zero	CY zero	CA	Cn zero
0.0422	16.7	122	8.5445	-0.0219	-0.00017	0.038626	-0.0109	0.129663	0	0	0.249	0
2.03	16.5	121	8.7674	0.122	0.033872	0.083378	-0.0124	-0.03228	0.81317	38.88035	0.544	-1.59798
4.08	16.4	121	8.80455	-0.0311	0.012004	0.099325	-0.013	-0.00463	0.144925	-0.50223	0.652	2.550811
6.07	16.3	120	8.80455	-0.125	0.065864	0.032402	-0.0232	-0.01697	0.527346	-6.35502	0.214	2.621275
8.05	16.3	120	8.87885	-0.0298	0.02468	0.086758	-0.0191	-0.01325	0.14837	0.295197	0.573	1.185247
10	16.4	121	8.916	-0.0803	0.141981	0.005042	-0.0431	-0.01237	0.681982	-2.04023	0.0331	0.997893
12	16.3	121	8.9903	-0.166	0.196834	0.032705	-0.084	-0.01517	0.785907	-4.75168	0.216	0.922826
14	16.4	121	8.9903	0.116	0.255931	0.047225	-0.0601	-0.01958	0.870379	4.944285	0.31	-0.9207
16.1	16.2	120	9.02745	-0.196	0.386738	0.029795	-0.0252	-0.02617	1.143251	-4.03803	0.198	1.31002
12	16.4	121	9.02745	-0.0469	0.210229	0.02803	-0.0722	-0.01657	0.830797	-0.30757	0.184	0.424639
8.02	16.5	121	8.9903	0.0941	0.088589	0.053031	-0.0285	-0.01517	0.52338	7.145579	0.346	-0.57732
4.01	16.6	122	8.95315	-0.0537	0.089126	0.083421	-0.00622	-0.01324	1.05979	-2.035	0.541	3.063548
0.0655	16.5	121	8.916	0.0182	0.021151	0.065752	-0.00805	0.393536		-2377.11	0.429	-2221.65

V=120 ft/s p=33.5 rps

Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zero	CY zero	CA	Cn zero
0.0699	16.5	121	12.51955	0.032	-0.02391	0.063606	-0.00776	0.129663	0	0	0.415	0
2.03	16.5	121	12.631	0.0224	0.029887	0.05533	-0.014	-0.03228	0.892057	3.473648	0.361	-3.67815
4.05	16.4	121	12.66815	-0.00771	-0.03839	0.04753	-0.0126	-0.00463	-0.12193	-2.70162	0.312	-0.25907
6.07	16.3	121	12.74245	-0.0471	0.066772	0.089787	-0.0209	-0.01697	0.502982	-3.19395	0.593	-0.04302
8.02	16.3	121	12.7796	-0.0626	0.055568	0.050723	-0.037	-0.01325	0.332529	-3.15579	0.335	-0.0929
10.1	16.3	121	12.81675	-0.124	0.14278	0.015595	-0.0709	-0.01237	0.553245	-4.41162	0.103	-0.06075
12	16.4	121	12.89105	-0.0145	0.182808	0.014503	-0.0907	-0.01517	0.571228	-0.80037	0.0952	-0.01383
14.1	16.4	121	12.8539	-0.00694	0.309249	0.033362	-0.0816	-0.01958	0.785987	-0.4222	0.219	1.030118
16.1	16.3	121	12.89105	0.0243	0.377013	0.043303	-0.0509	-0.02617	0.830797	0.353902	0.286	-0.93189
12.1	16.5	121	12.8539	-0.169	0.231435	-0.01793	-0.0946	-0.01657	0.69803	-4.65763	-0.117	-0.02981
8.04	16.6	122	12.7796	-0.091	0.081262	0.048726	-0.0375	-0.01517	0.436758	-4.13109	0.316	0.079441
4.03	16.5	121	12.7053	0.0133	0.05625	0.075102	-0.0168	-0.01324	0.665627	-0.41886	0.49	-1.44531
0.0705	16.4	121	12.631	0.0714	0.063069	0.088205	-0.0097	0.393536	41.71262	-1571.57	0.579	-1066.49

V=120 ft/s p=33.5 rps Repeat

Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zero	CY zero	CA	Cn zero
0.0662	16.3	121	12.51955	-0.0451	-0.02771	-0.00469	-0.00826	0.129663	0	0	-0.031	0
2.03	16.5	121	12.5567	-0.0925	-0.005	0.053031	-0.00635	-0.03228	0.384499	-2.33045	0.346	1.893834
4.02	16.3	121	12.59385	0.0426	-0.01178	0.034673	-0.0177	-0.00463	0.13541	7.251468	0.229	-1.02684
6.07	16.3	121	12.631	0.0107	0.002059	0.037247	-0.0226	-0.01697	0.1671	3.773577	0.246	-1.20648
8.05	16.3	121	12.66815	-0.047	0.122945	0.029676	-0.0315	-0.01325	0.635819	0.442553	0.196	0.040318
10	16.2	120	12.7053	-0.178	0.148827	-0.0155	-0.0528	-0.01237	0.596153	-3.76384	-0.103	0.558693
12.1	16.4	121	12.74245	-0.121	0.178237	-0.05317	-0.0889	-0.01517	0.571846	-1.55654	-0.349	-0.09774
14.1	16.3	121	12.7796	0.0477	0.328561	-0.04345	-0.0806	-0.01958	0.850952	2.479621	-0.287	-1.12083
16.1	16.3	121	12.7796	0.0293	0.395182	-0.05103	-0.048	-0.02617	0.884601	1.943511	-0.337	-0.78411
12.1	16.5	121	12.7796	-0.169	0.190053	-0.05916	-0.0873	-0.01657	0.599683	-2.7263	-0.386	0.129844
8.09	16.4	121	12.74245	-0.116	0.069772	0.001019	-0.0373	-0.01517	0.405206	-2.13636	0.00669	0.41376
4.06	16.3	121	12.66815	-0.0432	0.053902	0.022712	-0.00919	-0.01324	0.682919	1.170376	0.15	0.467737
0.051	16.4	121	12.29665	0.00734	-0.00408	0.003291	-0.00084	0.393536	16.23093	-2149.36	0.0216	-2148.37

V=172 ft/s p=21 rps

Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zero	CY zero	CA	Cn zero
0.0607	33.2	173	7.8015	-0.00206	-0.01977	0.08265	-0.0165	-0.08095	0	0	0.268	1198.561
2.03	33.2	173	7.8758	0.043	0.075557	0.086042	-0.0253	0.010554	1.80131	-8.10702	0.279	-2.89582
4.01	33.1	173	7.91295	-0.0631	0.050732	0.123294	-0.0212	-0.00898	0.672702	-11.7344	0.401	-0.00773
6.03	33	173	7.91295	-0.0382	0.128746	0.080926	-0.0261	-0.01349	0.945278	-6.09627	0.264	-0.19514
8.13	32.9	173	7.98725	-0.121	0.209036	0.083125	-0.0292	-0.02807	1.073376	-7.45218	0.272	0.352787
10.1	33.2	173	7.98725	-0.0654	0.274163	0.059829	-0.0541	-0.02665	1.100779	-4.06985	0.194	-0.16958
12.1	33	172	7.98725	-0.0881	0.358648	0.070197	-0.0581	-0.03172	1.182852	-3.90721	0.229	-0.08689
14.1	32.8	172	7.9501	-0.0456	0.487487	0.053928	-0.0538	-0.03567	1.375151	-2.22548	0.177	-0.07388
16.1	32.8	172	7.9501	-0.0866	0.600218	0.117301	-0.0674	-0.04095	1.472097	-2.73265	0.385	-0.09076
12.1	33.1	173	7.98725	-0.0364	0.350511	0.013067	-0.0672	-0.03449	1.160807	-2.34028	0.0425	-0.05198
8.06	33.1	173	7.98725	0.0272	0.162342	0.076559	-0.0336	-0.0247	0.856925	-1.17347	0.249	-1.44977
4.06	33.6	174	7.91295	0.0192	0.08427	0.120475	-0.0315	-0.01775	0.97453	-3.62077	0.386	-2.59893
0.0675	33.2	173	7.8758	-0.112	-0.02908	0.057361	-0.0143	-0.921	-5.29284	3833.078	0.186	7605.239

V=172 ft/s p=33 rps

Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zero	CY zero	CA	Cn zero
0.0664	33.1	172	12.2595	0.0312	0.009777	0.114377	-0.0181	-0.08095	0	0	0.372	0
2.03	33.1	172	12.3338	-0.0477	0.037511	0.082093	-0.0238	0.010554	0.333715	-18.942	0.267	4.390709
4.05	33.1	172	12.4081	0.0589	0.043353	0.108535	-0.0277	-0.00898	0.201291	-2.45178	0.353	1.081999
6.07	33.4	173	12.4081	0.0276	0.096799	0.116034	-0.0294	-0.01349	0.346621	-2.61727	0.374	0.766483
8.05	33.3	173	12.44525	-0.0772	0.20137	0.098365	-0.0479	-0.02807	0.575853	-4.4795	0.318	1.196216
10.1	33.3	173	12.4824	-0.0807	0.240654	0.051348	-0.1	-0.02665	0.551462	-3.66819	0.166	0.700386
12.1	33.2	173	12.5567	-0.231	0.370074	-0.00651	-0.139	-0.03172	0.716369	-5.72071	-0.0211	0.774098
14.1	33.3	173	12.631	-0.141	0.448519	-0.09867	-0.206	-0.03567	0.741926	-3.39792	-0.319	0.18938
16.1	33.3	173	12.66815	-0.202	0.578435	-0.12311	-0.201	-0.04095	0.839719	-3.72717	-0.398	0.288488
12.1	33.4	173	12.59385	-0.147	0.350585	-0.0013	-0.148	-0.03449	0.671456	-4.08997	-0.00418	0.498865
8.03	33.1	172	12.4824	-0.128	0.206002	0.086398	-0.0455	-0.0247	0.589801	-5.98237	0.281	1.42586
4.03	33.1	173	12.4081	-0.0357	0.027272	0.091932	-0.0255	-0.01775	0.106019	-7.28327	0.299	2.334544
0.0587	33.3	173	12.3338	0.0327	-0.07764	0.161467	-0.0175	-0.921	-36.3936	3234.42	0.522	3878.036

V=172 ft/s p-47.5 rps

Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zero	CY zero	CA	Cn zero
0.074	33.2	173	17.6091	-0.0024	0.0845	0.030839	-0.0148	-0.08095	0	0	0.1	326.0006
2.07	33.4	174	17.64625	-0.0371	0.103314	0.068256	-0.0192	0.010554	0.151361	-9.64027	0.22	-0.21648
4.03	33.3	174	17.72055	-0.00577	0.056297	0.054132	-0.0337	-0.00898	-0.12072	-2.95248	0.175	0.181633
6.03	33.2	173	17.79485	-0.0865	0.120582	0.022667	-0.0417	-0.01349	0.101591	-3.94199	0.0735	0.027324
8.03	33	173	17.79485	-0.238	0.18055	0.092268	-0.0691	-0.02807	0.205391	-5.66873	0.301	0.380198
10.1	33.1	173	17.86915	-0.0601	0.276719	0.022629	-0.129	-0.02665	0.323169	-1.73718	0.0736	-0.29198
12.1	33.3	173	17.94345	0.0364	0.454706	-0.06589	-0.193	-0.03172	0.513239	-0.13361	-0.213	-1.78665
14.1	33.2	173	18.01775	-0.181	0.48418	-0.14618	-0.243	-0.03567	0.475297	-2.45953	-0.474	-0.42983
16.1	33.3	173	18.0549	-0.0505	0.652673	-0.16703	-0.256	-0.04095	0.58848	-0.84327	-0.54	-0.14556
12.1	33.2	173	17.9063	-0.116	0.508851	-0.07031	-0.181	-0.03449	0.591708	-2.06174	-0.228	-0.3657
8.05	33.2	173	17.79485	-0.286	0.097144	0.045642	-0.0606	-0.0247	0.026667	-6.62138	0.148	0.611063
4.03	33.1	173	17.6834	-0.0353	0.225373	0.02183	-0.0232	-0.01775	0.600098	-3.77494	0.071	-0.07755
0.0836	33.3	173	17.64625	0.111	-0.03743	0.07331	-0.0191	-0.921	-24.947	1798.418	0.237	887.0129

Front and Rear Sections Spinning Only

V=120 ft/s p=15 rps

Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zeroed	CY zeroed	CA	Cn zeroed
0.0674	16.5	121	9.381125	0.0794	0.065139	0.035712	-0.0077	0.129663	0	0	0.233	0
2.05	16.5	121	9.4125	-0.0149	-0.01563	0.042609	-0.00362	-0.03228	-0.527	-12.6255	0.278	2.531988
4.03	16.5	121	9.443875	-0.083	0.064066	0.045981	-0.00811	-0.00463	-0.007	-16.282	0.3	2.87459
6.06	16.4	121	9.47525	0.00115	0.025288	0.034733	-0.0059	-0.01697	-0.259	-4.21762	0.228	-1.47774
8.04	16.4	121	9.538	-0.0434	0.122938	0.062916	-0.00963	-0.01325	0.382	-5.64528	0.413	0.946825
10	16.2	120	9.569375	-0.00908	0.14687	0.022271	-0.0183	-0.01237	0.551	-3.15561	0.148	0.668402
12	16.2	120	9.538	-0.0205	0.224218	0.016553	-0.0134	-0.01517	1.065	-2.93709	0.11	0.497796
14.1	16.2	120	9.538	0.059	0.28742	0.022873	-0.0301	-0.01958	1.485	-0.02429	0.152	-0.45624
16.1	16.2	120	9.506625	-0.169	0.37169	-0.01053	-0.0339	-0.02617	2.045	-5.76047	-0.07	0.872013
12.1	16.2	120	9.60075	-0.113	0.207665	0.05297	-0.021	-0.01657	0.955	-6.00511	0.352	0.955745
8.05	16.5	121	9.6635	-0.0505	0.119396	0.040156	-0.0121	-0.01517	0.354	-5.79288	0.262	0.948417
4.04	16.6	121	9.632125	0.0204	0.055357	0.032073	-0.00977	-0.01324	-0.066	-4.59104	0.208	0.20507
0.0601	16.6	122	9.538	-0.00482	0.01047	0.025134	-0.00399	0.393536	-0.3571	-578.341	0.163	-680.211

V=120 ft/s p=23 rps

Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zeroed	CY zeroed	CA	Cn zeroed
0.0686	16.5	121	14.4325	-0.00616	0.000282	0.053337	-0.00863	0.129663	0	0	0.348	-256.924
2.03	16.5	121	14.6835	-0.0761	0.025596	0.060848	-0.00053	-0.03228	0.16516	-4.96305	0.397	1.175114
4.03	16.5	121	14.49525	-0.0292	0.031114	0.023757	-0.00867	-0.00463	0.20116	-1.23756	0.155	0.168836
6.06	16.4	121	14.77763	-0.0365	0.098107	0.06444	-0.0139	-0.01697	0.64216	-0.59013	0.423	0.06567
8.05	16.3	121	14.90313	-0.129	0.104776	0.067529	-0.00638	-0.01325	0.69016	-3.63196	0.446	0.719858
10.1	16.2	120	14.90313	-0.0257	0.135283	0.068319	-0.0179	-0.01237	0.89716	-0.18904	0.454	-0.0109
12.1	16.2	120	14.87175	-0.12	0.173054	0.07494	-0.0245	-0.01517	1.14816	-2.17548	0.498	0.309933
14.1	16.2	120	14.6835	-0.0404	0.179073	-0.01731	-0.0342	-0.01958	1.18816	-0.281	-0.115	-0.03634
16.1	16.2	120	14.62075	-0.113	0.308488	-0.02272	-0.0558	-0.02617	2.04816	-1.3596	-0.151	0.047112
12.1	16.3	120	14.87175	0.0401	0.198348	0.057233	-0.0421	-0.01657	1.30816	1.376739	0.378	-0.70451
8.06	16.6	122	14.9345	-0.0176	0.056899	0.11904	-0.0116	-0.01517	0.36716	0.121994	0.772	0.00322
4.06	16.5	121	14.90313	-0.0243	0.036478	0.041842	-0.0102	-0.01324	0.23616	-0.3181	0.273	0.045457
0.0689	16.5	121	14.62075	-0.00102	-0.04154	0.099318	-0.0127	0.393536	-0.27284	-1514.38	0.648	-6338.4

V=120 ft/s p=33.5 rps												
Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zeroed	CY zeroed	CA	Cn zeroed
0.0698	16.5	121	21.05263	0.0476	-0.02621	0.070657	-0.0107	0.129663	0	0	0.461	0
2.04	16.5	121	21.084	0.00983	0.034026	0.089509	-0.0168	-0.03228	0.393	-0.5017	0.584	-2.76287
4.04	16.4	121	21.05263	0.0643	0.06383	0.110751	-0.0149	-0.00463	0.59	0.991257	0.727	-0.75525
6.07	16.3	121	21.14675	-0.0794	0.095692	0.088272	-0.01	-0.01697	0.803	-3.4083	0.583	0.413145
8.02	16.3	121	21.17813	-0.035	0.137632	0.062684	-0.0107	-0.01325	1.08	-1.6234	0.414	0.126966
10.1	16.3	121	21.084	-0.0735	0.171094	0.053751	-0.0201	-0.01237	1.301	-2.03015	0.355	0.185796
12.1	16.4	121	21.084	-0.0721	0.179761	0.02605	-0.0464	-0.01517	1.351	-1.61918	0.171	0.033117
14.1	16.5	121	20.80163	0.0207	0.262089	0.029734	-0.0601	-0.01958	1.881	-0.09807	0.194	-0.61042
16.2	16.4	121	20.77025	-0.00536	0.418934	-0.04464	-0.0968	-0.02617	2.921	-0.31459	-0.293	1.520427
12.1	16.5	122	21.02125	-0.158	0.180857	0.061767	-0.0307	-0.01657	1.351	-2.94316	0.403	0.352011
8.02	16.7	122	21.24088	-0.107	0.105021	0.063757	-0.0168	-0.01517	0.848	-3.20258	0.411	0.391094
4.03	16.4	121	21.17813	-0.00984	0.078607	0.08272	-0.0134	-0.01324	0.687	-2.04655	0.543	0.196145
0.0601	16.5	122	21.17813	0.0821	-0.00845	0.056863	-0.0141	0.393536	0.1159	-1117.12	0.371	265.76

V=120 ft/s p=23 rps		Repeat										
Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zeroed	CY zeroed	CA	Cn zeroed
0.0633	16.5	122	14.52663	-0.0361	-0.05748	0.053491	-0.00863	0.129663	0	0	0.349	0
2.05	16.5	122	14.52663	-0.0484	0.010284	0.080619	-0.0123	-0.03228	0.4421	2.65655	0.526	1.103811
4.04	16.5	122	14.52663	0.029	0.015787	0.077401	-0.00915	-0.00463	0.478	4.705723	0.505	-0.27803
6.07	16.4	121	14.58938	-0.123	0.088662	0.039304	-0.00987	-0.01697	0.957	-3.12067	0.258	1.118234
8.03	16.3	121	14.558	-0.0809	0.090089	0.074343	-0.00672	-0.01325	0.97	-1.07304	0.491	0.621638
10.1	16.4	121	14.58938	-0.131	0.118825	0.106333	-0.0126	-0.01237	1.155	-2.21337	0.698	0.716361
12.1	16.3	121	14.558	-0.128	0.135361	0.074645	-0.0314	-0.01517	1.269	-1.73192	0.493	0.447709
14.1	16.2	120	14.58938	-0.0114	0.308488	0.040931	-0.0432	-0.01958	2.425	0.853949	0.272	0.298435
16.1	16.2	120	14.558	-0.00996	0.325041	0.026184	-0.0699	-0.02617	2.535	0.885526	0.174	0.720652
12.1	16.4	121	14.62075	-0.0958	0.173667	0.038999	-0.0298	-0.01657	1.515	-0.96345	0.256	0.312389
8.03	16.5	122	14.62075	-0.0745	0.132117	0.063453	-0.0105	-0.01517	1.237	-0.78357	0.414	0.526635
4.01	16.7	122	14.6835	-0.126	-0.01073	0.105951	-0.012	-0.01324	0.3058	-5.09434	0.683	1.710922
0.0707	16.7	123	14.6835	0.059	-0.00064	0.072754	-0.0174	0.393536	0.37089	-1134.07	0.469	414.0229

V=172 ft/s	p=21 rps											
Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zeroed	CY zeroed	CA	Cn zeroed
0.0603	33.2	173	13.20888	-0.0149	-0.02045	0.070931	-0.0193	-0.08095	0	0	0.23	0
2.03	33.2	173	13.303	-0.00654	0.021526	0.122741	-0.0184	0.010554	0.1361	-8.59256	0.398	-3.03674
4.1	32.9	172	13.45988	-0.0684	0.139357	0.044313	-0.0209	-0.00898	0.5223	-6.36635	0.145	-0.53041
6.05	33.1	173	13.64813	-0.0289	0.124831	0.076866	-0.0175	-0.01349	0.4723	-2.76157	0.25	-0.55348
8.1	33.1	173	13.64813	-0.0237	0.148199	0.080864	-0.0226	-0.02807	0.5483	-1.56188	0.263	-0.39676
10.1	33	173	13.33438	-0.0145	0.226224	0.060388	-0.0327	-0.02665	0.8043	-1.12368	0.197	-0.19208
12.1	32.9	173	12.801	-0.142	0.320889	0.033311	-0.0627	-0.03172	1.1163	-3.20615	0.109	-0.1945
14.1	32.7	172	12.73825	-0.0452	0.419175	0.021627	-0.0487	-0.03567	1.4463	-1.18552	0.0712	-0.28116
16.1	32.7	172	12.801	-0.193	0.577126	0.024604	-0.0561	-0.04095	1.9663	-2.98125	0.081	-0.00852
12.1	33	173	12.86375	-0.085	0.364779	0.016216	-0.0597	-0.03449	1.2563	-2.1026	0.0529	-0.33057
8.02	33.3	173	13.49125	-0.093	0.136412	0.066814	-0.0157	-0.0247	0.5073	-3.455	0.216	-0.16228
4.03	33.4	174	13.49125	-0.0481	0.089042	0.071668	-0.0151	-0.01775	0.3533	-4.94722	0.231	-0.68523
0.0478	33.3	173	13.11475	0.0994	-0.04361	0.088467	-0.0238	-0.921	-0.0747	4236.148	0.286	-1372.85

V=172 ft/s	p=33 rps											
Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zeroed	CY zeroed	CA	Cn zeroed
0.0437	33.3	173	20.86438	-0.067	0.0219	0.10517	-0.0232	-0.08095	0	0	0.34	0
2.05	33.3	173	20.92713	-0.0853	-0.02215	0.107954	-0.00985	0.010554	-0.1424	-7.12181	0.349	1.095314
4.02	33.1	173	20.89575	-0.00753	0.071947	0.106998	-0.0187	-0.00898	0.1632	-0.41652	0.348	0.070808
6.03	33.2	173	20.9585	-0.0772	0.124591	0.09992	-0.0243	-0.01349	0.3332	-1.71494	0.324	0.158925
8.05	33.1	172	20.833	-0.157	0.182942	0.154963	-0.021	-0.02807	0.5242	-2.37121	0.504	0.357711
10.1	33.2	173	20.80163	-0.261	0.314563	0.005366	-0.037	-0.02665	0.9492	-3.29843	0.0174	0.495717
12.1	33.3	173	20.582	-0.182	0.337163	0.081971	-0.0872	-0.03172	1.0192	-1.83492	0.265	0.075916
14.1	33.2	173	20.39375	-0.365	0.502684	-0.0367	-0.0943	-0.03567	1.5592	-3.33188	-0.119	0.374926
16.1	33.2	173	20.26825	-0.289	0.58595	0.0066	-0.0905	-0.04095	1.8292	-2.24079	0.0214	0.211024
12.1	33.1	173	20.61338	-0.246	0.415079	0.04366	-0.0634	-0.03449	1.2792	-2.53041	0.142	0.284095
8.03	33.1	173	20.86438	-0.00422	0.164494	0.103001	-0.0301	-0.0247	0.4642	0.109177	0.335	0.797423
4.03	33.2	173	20.86438	-0.0902	0.11534	0.125517	-0.0155	-0.01775	0.3032	-2.8678	0.407	0.386875
0.0703	33.4	173	20.86438	-0.0179	0.018677	0.103004	-0.0132	-0.921	-0.0106	1681.758	0.332	91.15454

V=172 ft/s p=47.5 rps													
Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns		CN zeroed	CY zeroed	CA	Cn zeroed
0.086	33.4	174	30.7475	0.0602	0.083148	0.141165	-0.0125	-0.08095		0	0	0.455	0
2.03	33.4	173	30.81025	-0.148	0.050571	0.04933	-0.02	0.010554		-0.105	-13.2936	0.159	2.828586
4.03	33.3	173	30.7475	-0.0223	0.038047	0.10084	-0.0222	-0.00898		-0.145	-3.46877	0.326	0.831752
6.02	33.1	173	30.81025	-0.0827	0.063645	0.055959	-0.0263	-0.01349		-0.061	-3.17488	0.182	0.684385
8.03	33	173	30.71613	-0.132	0.165223	0.075715	-0.0292	-0.02807		0.271	-2.79001	0.247	0.593289
10.1	33.2	173	30.52738	-0.333	0.263061	0.041942	-0.0451	-0.02665		0.585	-4.05068	0.136	0.787049
12.1	33.2	173	30.40238	-0.159	0.279714	-0.08789	-0.106	-0.03172		0.639	-2.03651	-0.285	0.26687
14.1	33.2	173	30.33963	-0.309	0.533523	0.029668	-0.141	-0.03567		1.462	-2.70415	0.0962	0.334601
16.1	33.2	173	30.30825	-0.342	0.545859	-0.06785	-0.106	-0.04095		1.502	-2.52918	-0.22	0.387353
12.1	33.3	173	30.371	-0.244	0.330976	-0.1262	-0.105	-0.03449		0.802	-2.65513	-0.408	0.379055
8.06	33.5	174	30.59063	0.0288	0.133497	0.077173	-0.0399	-0.0247		0.161	-0.98892	0.248	0.02521
4.03	33.1	173	30.71613	-0.0717	0.113147	0.113455	-0.0193	-0.01775		0.1	-4.41212	0.369	1.015602
0.0551	33.3	174	30.81025	-0.0348	-0.09867	0.066814	-0.0184	-0.921		-0.587	1228.269	0.216	34.28005

V=172 ft/s	p=21 rps	Repeat											
Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns		CN zeroed	CY zeroed	CA	Cn zeroed
0.0664	33.2	173	13.20888	0.0161	-0.01018	0.121199	-0.014	-0.08095		0	0	0.393	0
2.05	33.2	173	13.1775	-0.0336	0.053044	0.125825	-0.0175	0.010554		0.205	-14.5883	0.408	5.180411
4.04	33.3	173	13.24025	0.00863	0.093416	0.13734	-0.0159	-0.00898		0.335	-4.13241	0.444	1.78291
6.06	33.3	174	13.33438	0.0687	0.094034	0.126204	-0.0225	-0.01349		0.337	-0.5145	0.408	0.796539
8.03	33.3	174	13.303	-0.00937	0.213124	0.167344	-0.0218	-0.02807		0.722	-2.05269	0.541	1.584209
10.1	33.1	173	13.303	-0.239	0.254889	0.057496	-0.0268	-0.02665		0.862	-6.4463	0.187	1.751974
12.1	33.2	173	13.1775	-0.213	0.360822	0.070622	-0.0648	-0.03172		1.203	-4.87182	0.229	1.170682
14.1	33.2	173	13.14613	-0.115	0.447172	0.117807	-0.0502	-0.03567		1.483	-2.65576	0.382	0.802062
16.1	33.1	173	13.08338	-0.0653	0.581111	0.085476	-0.0527	-0.04095		1.923	-1.61328	0.278	0.627396
12.1	33.4	173	13.11475	-0.162	0.24665	0.066704	-0.0592	-0.03449		0.828	-3.92577	0.215	1.029271
8.03	33.2	173	13.24025	-0.0882	0.21896	0.145254	-0.0206	-0.0247		0.743	-4.21448	0.471	1.495011
4.07	33.3	174	13.303	-0.0264	0.051348	0.176933	-0.024	-0.01775		0.199	-5.46356	0.572	2.492547
0.0602	33.4	173	13.303	0.0532	-0.06515	0.111691	-0.0205	-0.921		-0.177	3038.624	0.36	-970.22

All Sections Spinning at the Same Speed

V=120ft/s p=15 rps

Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zeroed	CY zeroed	CA	Cn zeroed
0.07	16.66	121.76	14.985	0.031508	-0.01274	0.062255	-0.00754	0.129663	0	0	0.402374	0
2.02	16.52	121.29	15.0849	0.032674	0.06128	0.033372	-0.01275	-0.03228	0.481722	4.322133	0.21751	-3.07948
4.00	16.43	121.12	15.21618	-0.04435	0.046807	0.013592	-0.01517	-0.00463	0.389101	-4.61879	0.089082	0.103044
6.07	16.31	120.64	15.31608	0.056291	0.072355	0.042028	-0.01744	-0.01697	0.559918	1.780204	0.277418	-1.04851
8.05	16.26	120.11	15.37883	-0.05851	0.107488	0.013466	-0.01916	-0.01325	0.794176	-2.45321	0.089183	0.073208
10.06	16.18	119.90	15.35323	-0.18605	0.136048	0.025442	-0.0295	-0.01237	0.987447	-5.27258	0.169264	0.619154
12.05	16.10	119.90	15.40193	-0.11775	0.225409	-0.00272	-0.05974	-0.01517	1.589993	-2.88205	-0.01819	0.022288
14.08	16.11	119.83	15.3334	0.029865	0.272847	-0.0062	-0.06664	-0.01958	1.905081	0.330859	-0.04141	-0.92667
16.10	16.00	119.31	15.2591	-0.07993	0.390892	-0.04385	-0.05942	-0.02617	2.712488	-1.38589	-0.29508	-0.07776
12.03	16.22	120.19	15.32763	-0.08035	0.21906	-0.02986	-0.06414	-0.01657	1.53622	-2.05029	-0.19816	-0.14036
8.05	16.29	120.57	15.5844	-0.05824	0.079392	0.018175	-0.01958	-0.01517	0.607126	-2.35787	0.120143	0.062211
4.01	16.52	121.32	15.4845	0.064687	0.051307	0.020947	-0.01527	-0.01324	0.416608	2.9369	0.136482	-1.52322
0.07	16.50	121.22	15.35323	0.06426	0.046374	0.021722	-0.00732	0.393536	0.38493	118.8604	0.141747	-6.78471

V=120 ft/s p=23 rps

Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zeroed	CY zeroed	CA	Cn zeroed
0.10	16.40	121.00	23.01415	0.0631	-0.10435	0.023917	-0.0112	0.129663	0	0	0.157	0
2.04	16.40	121.00	23.18258	-0.157	0.025593	0.053319	-0.0096	-0.03228	0.853	-15.6945	0.35	2.641561
4.07	16.40	121.00	23.3766	0.00273	0.095822	0.11136	-0.0118	-0.00463	1.314	-2.31497	0.731	-0.15243
6.03	16.40	121.00	23.40798	0.103	-0.06221	0.079521	-0.0226	-0.01697	0.276	1.592091	0.522	-0.69364
8.09	16.20	120.00	23.51365	-0.0752	0.077348	0.092095	-0.0277	-0.01325	1.199	-2.60812	0.612	0.283202
10.10	16.50	121.00	23.51365	-0.216	0.223772	-0.02789	-0.0455	-0.01237	2.145	-4.41147	-0.182	0.584756
12.10	16.50	121.00	23.4253	-0.105	0.225305	-0.01901	-0.0903	-0.01517	2.155	-2.11921	-0.124	0.002949
14.00	16.40	121.00	23.36833	-0.117	0.248314	0.025136	-0.0962	-0.01958	2.315	-1.93898	0.165	0.010043
16.10	16.30	121.00	23.23705	-0.00098	0.355815	-0.01229	-0.0833	-0.02617	3.035	-0.40283	-0.0812	7.967916
12.10	16.50	121.00	23.48805	-0.164	0.200782	0.036784	-0.0828	-0.01657	1.995	-2.90961	0.24	0.179942
8.04	16.50	121.00	23.54503	-0.107	0.102537	0.031727	-0.0231	-0.01517	1.354	-3.21461	0.207	0.428153
4.02	16.50	121.00	23.48228	0.0645	-0.01018	0.041996	-0.0248	-0.01324	0.6186	0.50914	0.274	-0.726
0.07	16.50	121.00	23.28825	0.0795	0.012614	0.117557	-0.00961	0.393536	0.7673	-931.301	0.767	212.7676

V=120 ft/s	p=33.5 rps											
Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zeroed	CY zeroed	CA	Cn zeroed
0.0504	16.5	121	33.55485	0.0944	0.018852	0.034485	-0.0108	0.129663	0	0	0.225	0
2.07	16.5	122	33.80913	-0.075	0.022837	0.074488	-0.0141	-0.03228	0.026	-7.75949	0.486	1.349207
4.01	16.5	121	33.80913	-0.15	0.051498	0.031573	-0.0177	-0.00463	0.213	-6.94637	0.206	1.204112
6.06	16.4	121	33.98333	-0.057	0.108161	0.093232	-0.0213	-0.01697	0.587	-2.57963	0.612	0.401293
8.05	16.4	121	33.94618	-0.125	0.065658	0.019195	-0.0442	-0.01325	0.308	-2.98116	0.126	0.389284
10	16.3	121	33.9891	-0.146	0.113407	-0.04406	-0.0741	-0.01237	0.626	-2.66749	-0.291	0.251129
12	16.5	121	33.84378	-0.356	0.203847	-0.00982	-0.115	-0.01517	1.207	-4.2093	-0.0641	0.474956
14.1	16.4	121	33.64975	-0.129	0.249837	-0.02971	-0.132	-0.01958	1.517	-1.69763	-0.195	0.010116
16.1	16.5	122	33.64975	0.111	0.335658	-0.08414	-0.122	-0.02617	2.067	0.312674	-0.549	-0.45799
12	16.7	122	33.77525	-0.303	0.156678	-0.05662	-0.122	-0.01657	0.887	-3.67659	-0.365	0.348806
8.06	16.5	121	34.02048	-0.0291	0.034332	0.04828	-0.0475	-0.01517	0.101	-1.55175	0.315	0.183708
4	16.7	122	34.0147	-0.0835	-0.05709	0.129375	-0.0251	-0.01324	-0.491	-4.73537	0.834	0.718651
0.0695	16.5	122	33.80913	-0.0226	0.015787	0.07035	-0.0101	0.393536	-0.02	-860.462	0.459	64.43356
V=120 ft/s	p=15 rps	Repeat										
Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zeroed	CY zeroed	CA	Cn zeroed
0.062	16.4	121	15.0593	-0.0253	-0.02529	0.044483	-0.0101	0.129663	0	0	0.292	0
2.03	16.4	121	15.17075	-0.0742	0.031077	0.013284	-0.00853	-0.03228	0.37	-2.13313	0.0872	2.97221
4.03	16.4	121	15.20213	-0.0166	0.034733	0.026964	-0.00473	-0.00463	0.394	0.860121	0.177	1.132535
6.05	16.3	121	15.24505	0.0114	0.155953	0.01234	-0.0183	-0.01697	1.196	2.313491	0.0815	-0.04319
8.02	16.3	121	15.1823	-0.0224	0.097357	-0.00533	-0.016	-0.01325	0.809	0.527387	-0.0352	0.517708
10.1	16.3	121	15.1567	-0.138	0.128548	0.004815	-0.0414	-0.01237	1.015	-2.60591	0.0318	0.748431
12	16.3	121	15.19385	-0.00119	0.269511	-0.02574	-0.0535	-0.01517	1.946	0.856565	-0.17	5.051887
14.1	16.3	121	15.16248	0.0116	0.331589	-0.03482	-0.0572	-0.01958	2.356	1.050328	-0.23	-0.80971
16.1	16.5	121	15.1311	-0.066	0.346387	-0.03203	-0.0571	-0.02617	2.426	-0.23421	-0.209	0.199623
12.1	16.3	121	15.231	-0.0756	0.158981	-0.00951	-0.0554	-0.01657	1.216	-0.72773	-0.0628	0.286344
8.05	16.5	121	15.3565	-0.202	0.118323	0.036018	-0.00985	-0.01517	0.938	-5.13232	0.235	1.629056
4.07	16.4	121	15.2822	-0.159	0.011761	0.025898	-0.0176	-0.01324	0.2432	-7.65338	0.17	2.569198
0.068	16.3	121	15.2822	0.0531	-0.02544	0.054962	-0.00819	0.393536	-0.002	-1205.73	0.363	398.0691

V=172 ft/s p=21 rps

Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zeroed	CY zeroed	CA	Cn zeroed
0.0675	33.3	173	21.38438	0.000467	0.011074	0.053204	-0.0155	-0.08095	0	0	0.172	-1841.13
2.07	33.3	174	21.353	-0.0179	0.104551	0.025457	-0.0161	0.010554	0.3022	-6.95653	0.0823	-0.19304
4.02	33.1	173	21.76665	0.0327	0.068565	0.082708	-0.0252	-0.00898	0.1872	-1.27124	0.269	-0.62545
6.06	33	173	21.99783	-0.0415	0.113419	0.039543	-0.0353	-0.01349	0.3342	-2.3048	0.129	-0.0528
8.09	32.8	172	21.94085	-0.112	0.166964	0.001045	-0.0432	-0.02807	0.5122	-2.61635	0.00343	0.093102
10.1	33.1	173	21.66425	-0.141	0.204772	0.008271	-0.0806	-0.02665	0.6302	-2.50456	0.0269	0.008205
12.1	32.9	172	21.3505	-0.144	0.394234	-0.04584	-0.123	-0.03172	1.2542	-2.09942	-0.15	-0.11338
14.1	33	173	20.9484	-0.423	0.484328	-0.11526	-0.18	-0.03567	1.5442	-4.45604	-0.376	0.205675
16.2	33.3	174	20.974	-0.313	0.538223	-0.10641	-0.144	-0.04095	1.7042	-2.91136	-0.344	0.09801
12.1	33.5	174	21.03675	-0.302	0.326741	-0.01083	-0.129	-0.03449	1.0142	-3.81344	-0.0348	0.162667
8.03	33.5	174	22.04075	-0.167	0.210359	0.03952	-0.0453	-0.0247	0.6402	-3.51643	0.127	0.246507
4.07	33.2	174	22.0292	0.0172	0.119657	0.075865	-0.0234	-0.01775	0.3522	-1.45476	0.246	-0.73714
0.068	33.2	173	21.64115	0.0515	-0.04657	0.075557	-0.0155	-0.921	-0.1868	1689.999	0.245	-568.967

V=172 ft/s p=33 rps

Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zeroed	CY zeroed	CA	Cn zeroed
0.0698	33.4	173	32.967	0.149	-0.01443	0.112311	-0.0245	-0.08095	0	0	0.362	0
2.06	33.4	173	32.99838	-0.0499	0.035679	0.125342	-0.0194	0.010554	0.1615	-11.8518	0.404	2.621903
4.02	33.4	173	33.2155	0.042	0.070117	0.094627	-0.0305	-0.00898	0.2725	-3.71841	0.305	0.763961
6.03	33.3	173	33.30963	-0.094	0.047945	0.112594	-0.0364	-0.01349	0.2015	-4.30093	0.364	0.909542
8.06	33.2	173	33.32695	-0.33	0.118424	0.160982	-0.0536	-0.02807	0.4305	-5.52636	0.522	1.08781
10.1	33	172	33.3385	-0.312	0.29918	0.039237	-0.111	-0.02665	1.0225	-4.27221	0.128	0.687491
12.1	33.4	173	33.01898	-0.0443	0.480892	-0.12007	-0.19	-0.03172	1.5965	-1.68406	-0.387	0.302558
14.1	33.1	172	32.4113	-0.325	0.648753	-0.14635	-0.249	-0.03567	2.1565	-3.16253	-0.476	0.254297
16.1	33	173	32.42863	-0.456	0.616139	-0.14223	-0.246	-0.04095	2.0565	-3.46881	-0.464	0.358378
12.1	33.4	173	33.02475	-0.185	0.316458	-0.12875	-0.194	-0.03449	1.0665	-2.64135	-0.415	0.247332
8.02	33.3	173	33.22705	-0.152	0.140433	0.084755	-0.0679	-0.0247	0.5005	-3.73037	0.274	0.691694
4.03	33.3	173	33.22705	-0.109	0.089395	0.101767	-0.0154	-0.01775	0.3355	-6.67461	0.329	1.54152
0.0742	33.4	173	33.14698	-0.0127	0.051812	0.142096	-0.0103	-0.921	0.2135	765.1659	0.458	147.3238

V=172 ft/s	p=47.5 rps											
Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zeroed	CY zeroed	CA	Cn zeroed
0.0699	33.3	173	50.15558	-0.0567	0.058462	0.064958	-0.011	-0.08095	0	0	0.21	0
2.07	33.4	174	50.29263	0.0264	0.028698	0.064222	-0.0296	0.010554	-0.0965	-0.22515	0.207	-0.16327
4.04	33.1	173	50.42968	0.0553	0.085476	0.061493	-0.0419	-0.00898	0.089	0.55005	0.2	-0.36718
6.04	33.2	173	50.4982	-0.114	0.156665	0.082341	-0.0497	-0.01349	0.319	-1.14157	0.267	0.07894
8.09	33.2	173	50.08705	-0.262	0.196447	0.004348	-0.0883	-0.02807	0.448	-1.7783	0.0141	0.162444
10.1	33.5	174	50.15558	-0.327	0.326741	-0.0557	-0.164	-0.02665	0.861	-1.78261	-0.179	0.066566
12.1	33	173	49.77658	-0.322	0.349452	-0.09073	-0.243	-0.03172	0.951	-1.46631	-0.296	-0.06409
14.1	33.2	174	49.6197	-0.444	0.496516	-0.17979	-0.308	-0.03567	1.421	-1.73561	-0.583	-0.04844
16.2	33.1	173	49.36293	-0.505	0.734844	-0.13774	-0.313	-0.04095	2.201	-1.70935	-0.448	-0.00757
12.1	33.4	173	49.71383	-0.416	0.33197	-0.21407	-0.254	-0.03449	0.881	-1.87132	-0.69	-0.00054
8.06	33.3	173	50.07878	-0.181	0.149713	0.009342	-0.0953	-0.0247	0.295	-1.24466	0.0302	0.045155
4.02	33.3	173	49.79313	-0.0223	0.079496	0.087229	-0.0303	-0.01775	0.068	-0.40033	0.282	0.029532
0.0719	33.7	174	50.29263	0.0504	0.056034	0.131477	-0.0212	-0.921	-0.01	724.36	0.42	-257.524

V=172 ft/s	p=33 rps	Repeat										
Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zeroed	CY zeroed	CA	Cn zeroed
0.0639	33.2	173	32.93563	-0.0529	-0.10054	0.05181	-0.00862	-0.08095	0	0	0.168	0
2.03	33.2	173	32.82995	-0.116	0.001129	0.095911	-0.0125	0.010554	0.32966	-6.47442	0.311	1.058751
4.01	33.3	173	32.89848	-0.0772	0.001355	-0.00974	-0.0239	-0.00898	0.33038	-2.03055	-0.0315	0.224397
6.07	33.2	173	32.97855	-0.0509	0.23623	0.010516	-0.0326	-0.01349	1.092	-0.9126	0.0341	0.047297
8.04	33.1	173	32.92735	-0.218	0.275797	-0.06457	-0.0636	-0.02807	1.223	-2.30499	-0.21	0.2484
10.1	33.2	173	32.90175	-0.452	0.311479	-0.09653	-0.115	-0.02665	1.336	-3.80797	-0.313	0.446345
12.1	33.4	173	32.78203	-0.147	0.387816	-0.09959	-0.203	-0.03172	1.576	-1.00242	-0.321	-0.19468
14.1	33.1	173	32.337	-0.168	0.596484	-0.17741	-0.25	-0.03567	2.266	-0.98469	-0.577	-0.23063
16.2	33.2	173	32.32295	-0.235	0.669217	-0.15574	-0.233	-0.04095	2.496	-1.18376	-0.505	-0.12456
12.1	33.2	173	32.39398	-0.436	0.450256	0.038241	-0.185	-0.03449	1.786	-3.05862	0.124	0.191359
8.05	33.2	173	32.79608	-0.192	0.199531	0.077099	-0.051	-0.0247	0.973	-2.06511	0.25	0.241798
4.04	33.1	173	32.8415	0.0334	0.110995	0.000149	-0.0342	-0.01775	0.687	0.487432	0.000484	-0.51821
0.0712	33.2	173	32.82418	-0.103	0.079874	0.091593	-0.00939	-0.921	0.585	943.3732	0.297	-163.398

All Sections Spinning - Mid Same Direction +10 rps

V=120 ft/s p=15 rps

Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zeroed	CY zeroed	CA	Cn zeroed
0	16.5	121	18.76853	0.0238	0.038011	0.047513	-0.0123	0.129663	0	0	0.31	0
2	16.6	122	18.8742	0.0291	0.042713	0.016191	-0.0129	-0.03228	0.029	3.86054	0.105	-3.7152
4	16.4	121	19.04263	0.000888	0.014061	0.007937	-0.0198	-0.00463	-0.1557	-0.94352	0.0521	-2.99896
6	16.4	121	19.21105	-0.00836	0.113645	0.017214	-0.0183	-0.01697	0.498	-0.51829	0.113	-0.32062
8	16.3	120	19.24243	-0.111	0.152925	-0.00129	-0.0304	-0.01325	0.762	-3.09413	-0.00849	-0.0907
10	16.1	120	19.1483	-0.137	0.17049	-0.06341	-0.0523	-0.01237	0.892	-3.06393	-0.424	-0.11121
12	16.1	120	19.1227	-0.0982	0.231807	-0.02572	-0.0799	-0.01517	1.302	-1.84317	-0.172	-0.35827
14	16.1	120	19.03435	-0.0235	0.291628	-0.05668	-0.0882	-0.01958	1.702	-0.41238	-0.379	-0.27665
16	16	119	19.0715	0.114	0.365615	-0.0489	-0.0659	-0.02617	2.212	1.509799	-0.329	-0.92141
12	16.1	120	19.02858	-0.0692	0.194419	-0.06177	-0.086	-0.01657	1.052	-1.33625	-0.413	-0.45928
8	16.3	121	19.31095	-0.0468	0.119614	0.008358	-0.0332	-0.01517	0.542	-1.41771	0.0552	-0.39739
4	16.4	121	19.14253	-0.0348	0.035495	-0.00655	-0.0111	-0.01324	-0.015	-2.30643	-0.043	-0.62069
0	16.5	121	18.9485	0.0341	-0.01298	0.053797	-0.0128	C.393536	-0.3327	30.85362	0.351	77.17961

V=120 ft/s p=23 rps

Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zeroed	CY zeroed	CA	Cn zeroed
0	16.6	122	26.63503	0.0156	0.019275	0.057516	-0.0192	0.129663	0	0	0.373	0
2	16.5	121	26.7663	-0.019	-0.03111	0.059468	-0.0169	-0.03228	-0.328	-0.16554	0.388	-3.14722
4	16.5	121	26.89758	-0.0316	0.046747	0.06238	-0.0192	-0.00463	0.18	-1.54237	0.407	-1.65804
6	16.4	121	26.99748	-0.0593	0.049206	0.03839	-0.0185	-0.01697	0.198	-1.39933	0.252	-1.00361
8	16.3	121	27.066	-0.104	0.090089	0.044212	-0.0455	-0.01325	0.47	-1.9383	0.292	-0.74481
10	16.3	120	27.07755	-0.0944	0.147777	-0.00436	-0.0708	-0.01237	0.851	-1.42175	-0.0288	-0.73232
12	16.5	121	27.05195	-0.133	0.24523	-0.05257	-0.112	-0.01517	1.475	-1.61445	-0.343	-0.6793
14	16.4	121	26.9892	-0.148	0.298586	-0.03504	-0.11	-0.01958	1.835	-1.4956	-0.23	-0.5467
16	16.3	120	26.85793	-0.0783	0.404267	-0.07253	-0.103	-0.02617	2.545	-0.61759	-0.479	-0.53737
12	16.4	121	27.05195	-0.116	0.191948	-0.03001	-0.101	-0.01657	1.135	-1.38875	-0.197	-0.66971
8	16.6	121	27.1659	-0.115	0.095911	0.058441	-0.047	-0.01517	0.497	-2.06845	0.379	-0.70558
5	16.4	121	27.09738	-0.0939	0.060326	0.051186	-0.0231	-0.01324	0.271	-2.59966	0.336	-0.9727
0	16.5	121	26.79768	0.0196	0.01476	0.071883	-0.0098	0.393536	-0.0287	-822.698	0.469	202.0842

V=120 ft/s p=33.5 rps

Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zeroed	CY zeroed	CA	Cn zeroed
0	16.6	122	37.6067	0.0625	-0.02082	0.094215	-0.0136	0.129663	0	0	0.611	0
2	16.6	122	37.6067	0.125	-0.01542	0.037624	-0.0271	-0.03228	0.035	4.911145	0.244	-1.88275
4	16.5	121	37.74375	-0.00244	-0.05334	0.033719	-0.0201	-0.00463	-0.213	-1.56501	0.22	0.348466
6	16.5	122	37.77513	-0.056	0.064373	0.083072	-0.0356	-0.01697	0.555	-1.75943	0.542	0.121451
8	16.3	121	37.81805	-0.236	0.036187	0.022106	-0.0454	-0.01325	0.374	-3.73936	0.146	0.500117
10	16.3	121	37.79245	-0.241	0.137632	-0.00996	-0.084	-0.01237	1.044	-3.03256	-0.0658	0.276173
12	16.6	122	37.7041	-0.142	0.148955	-0.05551	-0.136	-0.01517	1.101	-1.64722	-0.36	-0.07684
14	16.4	121	37.54723	-0.19	0.239173	-0.06017	-0.158	-0.01958	1.705	-1.73863	-0.395	-0.05207
16	16.4	121	37.48448	-0.155	0.300109	-0.08059	-0.132	-0.02617	2.105	-1.25282	-0.529	-0.02864
12	16.6	122	37.5786	-0.253	0.21125	-0.06507	-0.124	-0.01657	1.505	-2.58789	-0.422	0.133852
8	16.5	122	37.84943	-0.117	0.086597	0.002314	-0.0378	-0.01517	0.7	-2.13592	0.0151	0.219749
4	16.6	122	37.77513	-0.0551	0.034849	0.053815	-0.0234	-0.01324	0.361	-2.71197	0.349	0.25962
0	16.6	122	37.67523	-0.0164	-0.04934	0.078024	-0.00959	0.393536	-0.185	-750.172	0.506	12.77661

V=172 ft/s p=21 rps

Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zeroed	CY zeroed	CA	Cn zeroed
0	33.2	174	25.23893	0.0193	0.055819	0.061062	-0.014	-0.08095	0	0	0.198	0
2	33.3	174	25.3702	-0.0182	-0.04702	-0.02481	-0.0239	0.010554	-0.333	-7.0101	-0.0802	2.084019
4	33.2	174	25.50725	0.0293	0.113181	0.01434	-0.0317	-0.00898	0.186	-1.69645	0.0465	0.642104
6	33	173	25.5444	-0.061	0.095026	0.019251	-0.0335	-0.01349	0.129	-2.69346	0.0628	0.843805
8	33.3	173	25.5188	-0.186	0.183738	0.009465	-0.0609	-0.02807	0.413	-3.50587	0.0306	0.813525
10	33.4	174	25.27935	-0.195	0.253787	-0.03816	-0.106	-0.02665	0.637	-2.93537	-0.123	0.526181
12	33.1	173	25.12825	-0.235	0.427378	-0.13283	-0.175	-0.03172	1.209	-2.79456	-0.432	0.316315
14	33.1	173	25.14558	-0.11	0.461199	-0.09316	-0.217	-0.03567	1.319	-1.37842	-0.303	0.076926
16	33.2	173	24.63203	-0.403	0.629125	-0.13014	-0.199	-0.04095	1.859	-3.25347	-0.422	0.402836
12	33.4	174	25.25375	-0.278	0.397123	-0.11448	-0.157	-0.03449	1.099	-3.13898	-0.369	0.43285
8	33.3	174	25.48743	-0.171	0.153115	0.026045	-0.0504	-0.0247	0.314	-3.3714	0.0842	0.827877
4	33.2	174	25.57	0.0218	0.036082	-0.00981	-0.0254	-0.01775	-0.064	-1.66172	-0.0318	0.589779
0	33	173	25.31323	0.0402	-0.00044	0.053337	-0.0162	-0.921	-0.18243	2500.051	0.174	-827.496

V=172 ft/s p=33 rps

Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zeroed	CY zeroed	CA	Cn zeroed
0	33.3	173	36.682	0.0107	-0.01448	0.084445	-0.0106	-0.08095	0	0	0.273	0
2	33.5	174	36.78768	-0.162	0.102068	0.063792	-0.0196	0.010554	0.3748	-9.8421	0.205	2.911858
4	33.3	173	36.99325	-0.0663	0.123111	0.081971	-0.0363	-0.00898	0.4448	-2.78046	0.265	0.952409
6	33.1	173	36.96765	-0.17	0.164187	0.097159	-0.0436	-0.01349	0.5808	-3.10608	0.316	0.854209
8	33.4	174	37.04195	-0.287	0.124722	0.043125	-0.0773	-0.02807	0.4488	-3.28056	0.139	0.737303
10	33.1	173	37.01635	-0.307	0.174641	-0.10485	-0.143	-0.02665	0.6148	-2.78541	-0.341	0.462982
12	33.1	173	36.73975	-0.253	0.498095	-0.06887	-0.231	-0.03172	1.6668	-1.97054	-0.224	0.157491
14	33.2	173	36.23775	-0.321	0.502684	-0.21156	-0.273	-0.03567	1.6768	-2.05918	-0.686	0.129885
16	33.1	173	36.21215	-0.273	0.571887	-0.15035	-0.273	-0.04095	1.9068	-1.55424	-0.489	0.08007
12	33.5	173	36.14613	-0.348	0.29749	-0.0018	-0.218	-0.03449	1.0028	-2.56226	-0.0058	0.290148
8	33.2	173	36.84793	-0.222	0.11719	0.04225	-0.0744	-0.0247	0.4268	-2.70528	0.137	0.631707
4	33.4	173	36.89913	-0.0149	0.057397	0.082527	-0.0316	-0.01775	0.2318	-1.66907	0.266	0.972686
0	33.3	173	36.78768	0.0175	-0.04516	0.084445	-0.0113	-0.921	-0.0992	917.699	0.273	-381.174

V=172 ft/s p=47.5 rps

Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zeroed	CY zeroed	CA	Cn zeroed
0	33.3	173	53.53123	1.91	-0.30871	0.355722	0.032	-0.08095	0	1748.16	1.15	-346.126
2	33.5	174	53.537	1.72	-0.24677	0.126651	-0.0857	0.010554	0.205	43.97471	0.407	-9.72979
4	33.3	174	53.7112	-0.315	0.218383	0.089085	-0.0128	-0.00898	1.704	-3.95672	0.288	0.753072
6	33.3	174	53.84825	0.169	0.044852	0.162086	-0.0755	-0.01349	1.143	1.565137	0.524	-0.56037
8	33.1	173	53.84825	-0.374	0.207847	0.079634	-0.11	-0.02807	1.674	-2.2396	0.259	0.2289
10	33.2	174	53.8598	-0.328	0.376242	-0.07987	-0.181	-0.02665	2.218	-1.55505	-0.259	0.018716
12	33.2	174	53.87713	0.0306	0.487264	-0.03176	-0.279	-0.03172	2.578	0.268353	-0.103	-0.90475
14	33.1	173	53.70043	-0.469	0.488871	-0.18479	-0.375	-0.03567	2.588	-1.60211	-0.601	-0.11892
16	33.1	173	53.37513	-1.06	0.72562	-0.15834	-0.351	-0.04095	3.358	-3.31967	-0.515	0.294903
12	33.5	174	53.52045	-0.158	0.488555	-0.28847	-0.284	-0.03449	2.568	-0.53057	-0.927	-0.22463
8	33.3	174	53.62285	-0.422	0.113522	0.155899	-0.0563	-0.0247	1.365	-2.57268	0.504	0.407098
4	33.2	173	53.4858	0.492	0.166533	0.145871	-0.0936	-0.01775	1.538	6.600384	0.473	-1.78043
0	33.5	174	53.36858	0.515	-0.10549	0.360971	-0.179	-0.921	0.659	1373.488	1.16	-445.61

V=172 ft/s	p=47.5 rţ	Repeat											
Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns		CN zeroed	CY zeroed	CA	Cn zeroed
0	33.4	174	52.64618	0.0352	-0.06981	0.098971	0.0355	-0.08095		0	0	0.319	0
2	33.6	174	52.65195	0.798	-0.02703	0.186018	-0.0684	0.010554		0.1384	17.42065	0.596	-5.21584
4	33.4	174	52.7147	0.621	0.177154	0.04933	-0.0732	-0.00898		0.796	6.748936	0.159	-2.25113
6	33.2	173	52.8146	1.2	-0.20508	0.045026	-0.103	-0.01349		-0.44	9.569142	0.146	-2.62348
8	33.6	174	52.82615	-0.688	0.393259	-0.16323	-0.0561	-0.02807		1.485	-5.06197	-0.523	0.643356
10	33.3	174	52.7122	-0.466	0.120946	-0.09836	-0.0227	-0.02665		0.616	-2.92013	-0.318	0.34153
12	33.2	173	52.62963	-3.3	0.391661	-0.5181	-0.247	-0.03172		1.495	-14.8329	-1.68	2.472396
14	33.1	173	52.5355	-0.029	0.986966	-0.15927	-0.186	-0.03567		3.435	-0.41083	-0.518	-0.0144
16	33.2	173	51.32593	-0.76	0.755567	-0.21649	-0.242	-0.04095		2.675	-2.82085	-0.702	0.168181
12	33.5	174	51.41428	-0.454	0.550791	-0.2617	-0.116	-0.03449		1.995	-2.39535	-0.841	0.138212
8	33.4	174	52.79478	-2.28	-0.06639	0.006608	-0.0811	-0.0247		0.011	-15.5696	0.0213	2.726161
4	33.3	174	52.7147	-0.471	0.272824	0.04578	0.00111	-0.01775		1.107	-7.48266	0.148	0.99615
0	33.4	174	52.57188	-0.25	-0.09432	0.181808	-0.0261	-0.921		-0.079	446.2017	0.586	-104.111

All Sections Spinning - Mid Opp +10 rps

V=120 ft/s p=15 rps

Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zeroed	CY zeroed	CA	Cn zeroed
0	16.5	121	18.88575	-0.0301	-0.20691	0.073875	0.00187	0.129663	-1.35	0	0.482	0
2	16.6	122	19.01703	-0.00811	0.01912	0.037778	-0.00922	-0.03228	0.124	5.533383	0.245	-0.51253
4	16.5	122	19.05418	-0.0105	0.060848	0.070504	-0.00367	-0.00463	0.397	1.246775	0.46	-0.46862
6	16.5	121	19.15408	0.0389	0.091961	0.043988	0.00431	-0.01697	0.6	2.91383	0.287	-0.6399
8	16.4	121	19.29113	-0.0017	0.124918	0.074342	0.0132	-0.01325	0.82	1.062529	0.488	-1.09941
10	16.3	121	19.36543	0.0374	0.135361	0.053599	0.0295	-0.01237	0.894	1.623571	0.354	-0.12476
12	16.2	120	19.4711	-0.0117	0.210675	0.074789	0.0479	-0.01517	1.4	0.565302	0.497	-0.25646
14	16.3	121	19.50825	0.032	0.302821	0.000666	0.0278	-0.01958	2	1.180609	0.0044	-0.0672
16	16.2	120	19.5198	0.141	0.383729	0.00456	-0.00889	-0.02617	2.55	2.490476	0.0303	-0.59909
12	16.3	120	19.43395	0.0645	0.20289	0.059807	0.0515	-0.01657	1.34	1.864136	0.395	-0.06151
8	16.5	121	19.3968	0.0543	0.099931	0.029428	0.0145	-0.01517	0.652	2.510931	0.192	-0.43831
4	16.6	122	19.32828	-0.0101	0.026059	0.024363	-0.00387	-0.01324	0.169	1.679808	0.158	-0.49921
0	16.6	122	19.22838	-0.0495	0.03269	0.009606	-0.00838	0.393536	0.212	-55.7801	0.0623	-73.6778

V=120 ft/s p=23 rps

Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zeroed	CY zeroed	CA	Cn zeroed
0	16.6	122	26.63503	0.0227	-0.03732	0.078949	-0.0101	0.129663	0	0	0.512	0
2	16.6	122	26.7407	0.0434	0.015728	0.049035	-0.0132	-0.03228	0.344	3.841598	0.318	-2.56514
4	16.5	121	26.90913	0.0737	0.025443	0.065752	-0.00516	-0.00463	0.408	2.020082	0.429	-1.0822
6	16.4	121	26.9149	0.0149	0.035952	0.094451	0.00439	-0.01697	0.478	0.223202	0.62	-0.36812
8	16.4	121	27.05195	0.0224	0.129184	0.055604	0.0184	-0.01325	1.09	0.235306	0.365	-0.16411
10	16.4	121	26.5653	0.0282	0.15234	0.090337	0.0387	-0.01237	1.242	0.263168	0.593	-0.01213
12	16.3	121	27.22615	-0.0655	0.137027	0.133544	0.0608	-0.01517	1.147	-0.88876	0.882	0.178553
14	16.3	120	27.2633	-0.0261	0.298279	0.062381	0.042	-0.01958	2.212	-0.3019	0.412	-0.07172
16	16.3	121	27.27485	0.0711	0.336132	0.036641	-0.0207	-0.02617	2.462	0.675216	0.242	-0.37702
12	16.4	121	27.2633	-0.0994	0.225463	0.139086	0.0673	-0.01657	1.722	-1.27471	0.913	0.296698
8	16.6	122	27.15763	-0.00293	0.088509	0.052581	0.0145	-0.01517	0.816	-0.18904	0.341	-0.64105
4	16.8	122	26.9892	0.109	-0.00342	0.070693	-0.0112	-0.01324	0.2201	3.577348	0.453	-1.4812
0	16.6	121	26.70105	-0.0163	0.07679	0.070006	-0.011	0.393536	0.74	-1186.57	0.454	-66.7795

V=120 ft/s p=33.5 rps

Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zeroed	CY zeroed	CA	Cn zeroed
0	16.6	122	37.4812	0.0199	-0.03608	0.086659	-0.00733	0.129663	0	0	0.562	0
2	16.6	122	37.54973	-0.0418	-0.00076	0.053969	-0.0101	-0.03228	0.2291	-1.49012	0.35	-0.44978
4	16.5	122	37.49275	-0.0536	0.028814	0.044295	-0.00604	-0.00463	0.422	-1.81852	0.289	-0.05184
6	16.5	122	37.59265	0.106	0.043222	0.06284	0.00303	-0.01697	0.516	1.800624	0.41	-0.59197
8	16.4	121	37.59843	-0.00969	0.093994	0.093537	0.0202	-0.01325	0.851	-0.2136	0.614	-0.17357
10	16.2	120	37.7041	-0.0389	0.151987	0.113614	0.0532	-0.01237	1.244	-0.48375	0.755	0.084086
12	16.5	121	37.804	-0.111	0.197716	0.147444	0.0888	-0.01517	1.524	-1.00203	0.962	0.314133
14	16.5	121	37.7784	-0.0618	0.312668	0.121695	0.062	-0.01958	2.274	-0.46135	0.794	0.099465
16	16.5	122	37.80978	-0.123	0.33106	0.099625	0.00704	-0.02617	2.394	-0.75939	0.65	0.076234
12	16.6	122	37.74703	-0.0123	0.229754	0.10948	0.0769	-0.01657	1.724	-0.13584	0.71	-0.1746
8	16.5	121	37.6042	0.00515	0.089969	0.085064	0.0262	-0.01517	0.821	0.005456	0.555	0.28254
4	16.6	122	37.56705	0.0136	0.062913	0.069697	-0.00094	-0.01324	0.642	0.180888	0.452	-0.42034
0	16.6	122	37.62403	0.0121	-0.10023	0.063221	-0.0201	0.393536	-0.416	-396.129	0.41	284.1572

V=120 ft/s p=33.5 rp Repeat

Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zeroed	CY zeroed	CA	Cn zeroed
0	16.5	122	37.21865	-0.141	-0.0423	0.091348	-0.00372	0.129663	0	0	0.596	0
2	16.5	122	37.1303	0.0121	0.042915	0.099931	-0.00974	-0.03228	0.556	9.460269	0.652	-2.43638
4	16.4	121	37.1303	0.1	0.033058	0.111056	-0.00561	-0.00463	0.493	6.487031	0.729	-1.31134
6	16.3	121	37.13608	0.0804	0.042698	0.092058	0.00951	-0.01697	0.558	4.225315	0.608	-0.7473
8	16.3	121	37.0791	-0.0509	0.087061	0.125974	0.0296	-0.01325	0.851	1.376687	0.832	-0.14597
10	16.3	121	37.27313	0.0537	0.274053	0.130667	0.049	-0.01237	2.086	2.186967	0.863	-0.19836
12	16.3	121	37.2533	-0.129	0.225602	0.190777	0.0764	-0.01517	1.766	0.239648	1.26	0.180681
14	16.2	121	37.31605	-0.0276	0.278391	0.082464	0.0398	-0.01958	2.126	1.018287	0.548	-0.15811
16	16.2	120	37.34743	-0.067	0.353632	0.082314	-0.00293	-0.02617	2.626	0.660969	0.547	-0.12268
12	16.2	121	37.34743	0.0645	0.213684	0.143409	0.0837	-0.01657	1.696	1.965893	0.953	-0.05511
8	16.3	121	37.21038	-0.0282	0.131273	0.111893	0.0242	-0.01517	1.143	1.700732	0.739	-0.2621
4	16.5	122	37.16168	0.0845	0.021917	0.088283	0.00173	-0.01324	0.419	6.313188	0.576	-1.20436
0	16.6	122	37.25003	0.0837	-0.0058	0.103312	-0.0157	0.393536	0.2384	-263.542	0.67	89.1808

V=172 ft/s p=21 rps

Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zeroed	CY zeroed	CA	Cn zeroed
0	33.5	174	24.89958	-0.0522	-0.01111	0.032052	-0.0139	-0.08095	0	0	0.103	0
2	33.3	174	25.15635	0.0223	-0.00764	0.005011	-0.0147	0.010554	0.011	-0.93168	0.0162	-0.10496
4	33.1	173	25.1679	-0.0236	0.10915	0.056266	-0.00526	-0.00898	0.3907	-1.19698	0.183	0.140518
6	33.1	173	25.27358	0.0787	0.171873	0.045197	-0.0006	-0.01349	0.5947	1.159643	0.147	-0.28939
8	33.2	174	25.2166	0.0601	0.200457	0.081725	0.0184	-0.02807	0.6857	0.823748	0.265	-0.07406
10	33.2	173	25.20255	0.141	0.277555	0.115031	0.0415	-0.02665	0.9357	1.523019	0.373	-0.1508
12	33.1	173	25.18273	-0.154	0.359735	0.202927	0.0699	-0.03172	1.2057	-1.38749	0.66	0.437889
14	33.4	174	25.063	0.214	0.502609	0.146129	0.116	-0.03567	1.6557	1.744351	0.471	-0.00459
16	33.6	175	24.88053	0.124	0.59301	0.165419	0.13	-0.04095	1.9357	0.948561	0.53	0.207463
12	33.1	173	24.90035	0.0997	0.436602	0.090702	0.0728	-0.03449	1.4557	0.979722	0.295	0.092318
8	33.5	175	25.22815	0.0515	0.185153	0.070949	0.0255	-0.0247	0.6307	0.652973	0.228	0.011212
4	33.3	173	25.27935	-0.0209	0.128679	0.005351	-0.00971	-0.01775	0.4517	-0.87125	0.0173	0.0903
0	33.1	173	25.10515	0.0955	0.006764	0.004489	-0.0197	-0.921	0.0577	1715.603	0.0146	-481.249

V=172 ft/s p=33 rps

Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zeroed	CY zeroed	CA	Cn zeroed
0	33.2	173	36.79345	-0.0937	-0.11226	0.085117	-0.0172	-0.08095	0	0	0.276	0
2	33.3	173	36.8306	0.026	0.0365	0.113831	-0.0129	0.010554	0.482	1.049516	0.368	-0.28153
4	33.3	173	36.84215	0.0508	0.053204	0.119708	-0.016	-0.00898	0.536	1.359339	0.387	-0.38383
6	33.4	173	36.8537	0.0259	0.080976	0.202905	0.00886	-0.01349	0.625	0.653137	0.654	-0.0625
8	33.1	173	36.928	-0.0741	0.253967	0.141742	0.0274	-0.02807	1.19	-0.31339	0.461	0.127991
10	33.1	173	36.87103	0.0989	0.245665	0.162342	0.0559	-0.02665	1.163	1.039668	0.528	-0.01998
12	33.1	173	36.94533	-0.00574	0.4489	0.262883	0.11	-0.03172	1.824	0.242561	0.855	-1.12584
14	33.2	173	36.88835	-0.0705	0.462592	0.300068	0.158	-0.03567	1.864	-0.11848	0.973	0.175573
16	33.3	173	36.36903	-0.179	0.705258	0.225806	0.191	-0.04095	2.644	-0.59541	0.73	0.369374
12	33.4	174	36.28895	-0.0131	0.390918	0.288845	0.0932	-0.03449	1.624	0.216981	0.931	-0.37329
8	33.5	174	36.84543	0.0713	0.210359	0.135986	0.0281	-0.0247	1.04	1.022585	0.437	-0.07682
4	33.1	173	36.89663	0.0319	0.084246	0.106998	-0.0138	-0.01775	0.638	1.174828	0.348	-0.36431
0	33.5	173	36.8537	-0.149	-0.14314	0.061614	-0.0212	-0.921	-0.096	604.0831	0.198	-93.2954

V=172 ft/s p=47.5 rps

Alpha	Qc	Velocity	p eff	Yawfor	Normfor	Axialfor	Yawmom	Ns	CN zeroed	CY zeroed	CA	Cn zeroed
0	33.3	174	53.76818	1.66	0.383561	-0.09156	-0.0331	-0.08095	1.24	1105.095	-0.296	-233 228
2	33.3	174	53.8111	0.624	-0.14848	0.066814	0.0295	0.010554	-0.48	15.79454	0.216	-2.96127
4	33.2	173	53.72275	-0.477	0.205699	0.081416	-0.0118	-0.00898	0.667	-6.01842	0.264	1.177759
6	33.3	174	53.62863	0.36	0.009249	0.193946	0.0128	-0.01349	0.0299	3.232365	0.627	-0.61741
8	33.3	173	53.7343	-0.014	0.18745	0.119399	0.0515	-0.02807	0.606	0.090381	0.386	-0.13289
10	33.1	173	53.90273	-0.331	0.381258	0.113762	0.126	-0.02665	1.24	-1.56497	0.37	0.527027
12	33.3	173	54.01418	-0.299	0.368095	0.242819	0.0922	-0.03172	1.19	-1.13795	0.785	0.355455
14	33.2	174	54.01995	-0.0418	0.755567	0.238389	0.165	-0.03567	2.45	-0.02244	0.773	0.036517
16	33.2	173	53.96298	-0.241	0.493432	0.38241	0.179	-0.04095	1.6	-0.63867	1.24	0.296707
12	33.2	174	53.81438	0.15	0.308086	0.178252	0.178	-0.03449	0.999	0.795341	0.578	0.16654
8	33.2	173	53.6088	0.0331	0.162216	0.178561	0.022	-0.0247	0.526	0.373353	0.579	0.011544
4	33.4	174	53.66	-0.236	0.022059	0.043746	-0.0431	-0.01775	0.0711	-2.81613	0.141	0.396762
0	33.3	174	53.77395	0.309	-0.12528	0.273442	0.0284	-0.921	-0.405	674.5593	0.884	-115.912

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Vita

Captain Karen A. Naselius was born on 11 April 1961 in Evanston, Illinois. She graduated from New Trier West High School in Northfield, Illinois in 1979 and attended the University of Illinois, graduating with a Bachelor of Science in Aeronautical and Astronautical Engineering in May 1984. Upon graduation, she received a regular commission in the USAF and was stationed at Wright-Patterson AFB, Ohio. She began as an Threat Integration Engineer for AFSC's Foreign Technology Division where she evaluated foreign technology threats to US tactical aircraft systems until September 1988. She was then reassigned to the B-1B System Program Office as a Weapons Integration Systems Engineer. There she was responsible for integrating the Short Range Attack Missile II (SRAM II) on to the B-1B weapons carriage until entering the School of Engineering, Air Force Institute of Technology, in May 1991.

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